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Preliminary Design And Economics Of Biorefinery Schemes Based On The Noncatalytic Cracking Of Triglyceride Oils

Shelby Amsley-Benzie

PRELIMINARY DESIGN AND ECONOMICS OF BIOREFINERY SCHEMES BASED ON THE NONCATALYTIC CRACKING OF TRIGLYCERIDE OILS

by

Shelby Amsley-Benzie
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This thesis, submitted by Shelby Amsley-Benzie in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

Dr. Wayne Seames
Dr. Wayne Seames, Chairman

Dr. Frank Bowman
Dr. Frank Bowman

Dr. Ali Alshami
Dr. Ali Saleh Alshami

This thesis is being submitted by the appointed advisory committee as having met all of the requirements of the School of Graduate Studies at the University of North Dakota and is hereby approved.

Grant McGimpsey
Grant McGimpsey
Dean of the School of Graduate Studies

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ABSTRACT

Recent years have seen an increased demand for renewable transportation fuels. First generation biofuels were the first response to this increased demand, but they are physically and chemically different from their petroleum counterparts. These major differences have motivated the development of processes that are capable of producing drop-in compatible biofuels. These drop-in fuels are engine ready, and have essentially the same properties as their petroleum equivalents. The development of second generation fuels include cellulose-derived fuels, lignin-derived fuels, direct photosynthetic derivatives, lipid-derived fuels, and feedstock-flexible bioconversion processes. The focus of this thesis is lipid-derived drop-in ready fuels.

One of the new technologies for producing drop-in compatible renewable fuels and associated chemicals is based on the non-catalytic cracking of fatty acid based oils, such as animal fats and waste cooking oils, as well as triglyceride based (TAG) oils such as crop oils, bacteriological oils, and algae lipids. Research through the University of North Dakota has been conducted on the each of the various unit operations needed to design a comprehensive facility capable of producing drop-in compatible renewable fuels and various by-product chemical products in a variety of configurations using this technology.

This research included determination of the optimized yields of organic liquid products (OLP) produced from the conversion of the inlet oil. This OLP can then be further processed and separated into transportation fuels such as jet fuel and diesel fuel as

well as fuel intermediates like naphtha and butane plus other by-products. A model that accurately represents the reactions completed by the noncatalytic cracking of the TAG oils was developed through substantial testing in continuous, scalable reactors. However, the various pieces of technology had not been assembled into an integrated biorefinery concept.

A preliminary design, cost estimate, and economic analysis on three biorefinery alternatives was performed based on the previously gathered data to determine the profitability of implementing a plant that processes renewable transportation fuels through noncatalytic cracking of TAG oil. These three alternatives include a base design, fatty acid recovery design, and a heavy end processing design. Following the preliminary design and economic assessment, an economic hazards analysis was then performed to evaluate the hazards to each investment.

Both the fatty acid recovery biorefinery and heavy end processing biorefinery alternative were found to be economically feasible. In addition, both alternatives have the potential to remain economically feasible while taking into account raw material and product price fluctuations. While a fully configured biorefinery combining these two alternatives leads to an even higher profitability (NPV@ 12% of $2.5 billion ± 40%). Also, the integration of any of the biorefinery alternatives with a previously developed soybean oil processing plant showed that starting from oil seeds results in economically feasible alternatives with and without additional byproduct production due to gains in oil recovery facilities compared to food grade oil.

This work demonstrates the technical and commercial feasibility of these technologies and provides a roadmap towards commercial scale development.

CHAPTER I
INTRODUCTION AND BACKGROUND

This thesis describes the method used to compile previously collected data on the conversion of triglyceride oils (TAG) into drop-in compatible biofuel products through noncatalytic cracking and refinement and the use of these data to conduct a preliminary design and economic analysis to evaluate commercial potential. The cracking and refinement process is known as the noncatlytic cracking process (NCP). Fundamental data generated by previous researchers were used to develop the preliminary process design for a fully operational world scale NCP-of-TAG oils biorefinery that converts TAG oils into transportation fuels. A number of options were considered, allowing for the recovery of high volume, high value by-products. The developed processes were then used to perform an economic assessment of the most feasible alternatives.

The first chapter of this thesis provides a review of first and second generation biofuels. It then goes through the relevant economic history of the raw materials, transportations fuels, and other byproducts produced by the processes. Finally, a review the basic concepts and previous experimental work surrounding the individual subsets of a TAG oil biorefinery scheme is presented.

The second chapter describes the scope of work required to produce a preliminary design, cost estimate, and economic assessment surrounding NCP-of-TAG oil plants. The third chapter documetns how the methods described in Chapter II were used to develop the preliminary design and economic assessment of the base design, a biorefinery based on the noncatalytic cracking of triglyceride oils that maximizes transportation fuel production. Soybean oil is used as the example raw material as it is the most commonly available U.S. TAG oil currently cultivated. The fourth chapter follows the same procedure to show the process that models C_1-C_{12} fatty acid recovery as higher margin byproducts. Finally, chapter five provides designs for a biorefinery alternative that uses heavy end processing to produce mesophase pitch from tars. This pitch is a precursor for carbon fibers

Chapter six of this thesis shows the results of a hazard analysis performed for each of the three alternatives described in chapters III-V, while chapter seven provides a comparison of the three designs produced to provide insights into the key economic drivers of the process. This includes an assessment of the economic benefits if a TAG oil processing facility is integrated with one of the NCP of TAG oil biorefineries. The eighth chapter summarizes the conclusions found from this work along with recommendations for both future research as well as for development to commercialization.

I.A. Background

Industrialism has led to a dramatic increase in the release of carbon previously fixed below ground into the atmosphere in the form of carbon dioxide. These carbon dioxide emissions trap heat, steadily drive up the planet's average temperature, and create the potential for significant and harmful impacts to our health, environment, and climate. If left unchecked, these emissions are expected to cause irreversible damage to communities throughout the United States and the world. This damage includes increased urban air pollution, flooding due to rising sea-levels, erosion in coastal communities, extreme weather including more intense droughts and hurricanes, reduced productivity of some agricultural regions, and loss of treasured landscapes such as coral reefs. Over the last 30 years there has been a large increase in carbon emissions from the use of gas, liquid, and solid fuels. The major contributors to these sources are coal, petroleum, and natural gas [1].

The United States alone contributes nearly 25% of the world's annual global CO_2 emissions [2], with electric power generation and transportation fuel use each accounting for roughly one third of these emissions. The majority of the electricity is generated by coal-fired power plants, which produce roughly 25% of the total U.S. CO_2 emissions, while the majority of transportation emissions come from the combustion of petroleum-based liquid products such as gasoline, jet fuel, and diesel fuel.

Transportation fuel CO_2 emissions also account for roughly 25% of the U.S. total emissions [2]. In contrast, most renewable energy sources do not emit carbon that originates in the ground (fossil carbon). These renewable energy sources include wind, solar, geothermal, hydroelectric, and biomass. Reduction in the use of fossil-fuel energy sources and increased use of renewable energy sources will help to reduce overall fossil-derived CO_2 emissions.

Currently, 92% of the U.S. transport sector runs on petroleum. The reason for this dominance is because transportation fuels derived from petroleum pack a lot of energy into a small volume and weight [3]. First generation renewable fuels (biofuels), on the other hand, have a lower energy density and energy transformation efficiency than their petroleum counterparts, making them a less attractive fuel source.

The development of higher density sustainable biofuels is also important over the coming years because the demand for transportation fuels is increasing while the major supply (crude oil) will decrease. Eventually all crude oil reserves in the world will be exhausted, and as supplies dwindle the cost of crude oil prices will drastically increase. This in turn will lead to substantial economic disruptions.

Current biofuel processes only supply one of the three major transportation fuels (gasoline, kerosene, and diesel fuel); ethanol supplements gasoline and biodiesel supplements diesel fuel. In order for biofuels to be implemented into the economy without causing market disruptions, all three major petroleum derived fuels must be produced in roughly the same ratio as crude oil. If these ratios are skewed (if the demand for one product stays the same while the other two are reduced), then either 1) crude oil imports will not be substantially impacted or 2) the demand for one or more of the products will exceed supply, causing price increases and shortages [4]. One of the major challenges of this problem is creating a renewable biofuel to replace jet fuel. Jet fuel has the most challenging product specifications that must be met in order for the fuel to be able to be used directly in airplane engines.

The work developed in this thesis provides an answer to the renewable fuels problem. This work shows the capability to produce all three renewable transportation fuels that could replace their petroleum counterparts. This in turn will help reduce our dependence on petroleum, as well as reduce the amount of fossil carbon emissions produced from petroleum-based transportation fuels.

I.B. Biofuels

Recent years have seen an increased quantity of U.S. CO_2 emissions from transportation [3]. This is due to the increased demand for travel, and the limited gains in fuel efficiency across the U.S. vehicle fleet. As the demand for travel increases, so does the demand for renewable transportation fuels to try to help solve the carbon dioxide emission crisis, and lower the U.S. dependence on petroleum. First generation biofuels, which include ethanol and biodiesel, were the first response to this increased opportunity. The problem with first generation biofuels is that they are physically and chemically different from their petroleum counterparts. These major differences motivated the development of processes capable of producing drop-in compatible renewable fuels (second generation biofuels). These second generation biofuels are engine ready, and have essentially the same properties as their petroleum counterparts.

I.B.1. First Generation Biofuels

Ethanol, the largest volume first generation biofuel, is produced through fermentation of plant based starches and sugars. The fermentation of sugar into ethanol is one of the earliest organic reactions learned by man, and dates back over 7000 years ago [5]. Fuel ethanol has been integrated into the infrastructure of many countries, most notably the United States, China, and Brazil, as well as the European Union 27 [6]. It is formed from the fermentation of saccharide feedstocks, and has a high octane rating which provides premium blending properties with gasoline. This long used process has led to the development of the fuel ethanol industry, which is produced primarily from corn starch within the United States. The majority of gasoline in the United States is blended with 10% ethanol in order to attain the standard 87 octane rating requirement. Fuel ethanol was originally produced from starch and sugar-based feedstocks, but in recent years the use of cellulosic feedstock has also been commercialized to produce fuel ethanol [7].

The best advantage of ethanol is its high octane rating. Higher octane rating indicates resistance of a fuel to engine knocking, which in turn boosts fuel economy. Ethanol can increase fuel economy 66% to 80% for engines that are optimized for ethanol burning (although, most vehicles currently in service do not see these large gains). The largest drawback to ethanol blended fuel is the lower energy density compared to pure petroleum gasoline. Denatured ethanol (98% ethanol) contains roughly 30% less energy than gasoline per gallon [7] due to the presence of oxygen in the alcohol groups. This energy density is also significantly lower than kerosene and other diesel fuels, making it unlikely that fuel ethanol could adequately fulfill the needs that liquid transportation fuels are required to satisfy. Also, there is a lack of true miscibility in gasoline, which limits blending capabilities.

Biodiesel is a first generation renewable fuel manufactured from vegetable oils, animal fats, or recycled restaurant greases. It is formed industrially from the base-catalyzed transesterification of TAG oils, but can also be produced through esterification pretreatments, transesterification of oils through acid catalysis, and heterogeneous catalysis [8].

Biodiesel has both advantages and disadvantages compared to its petroleum counterpart, diesel fuel no. 2. The primary advantages of biodiesel are very similar to those of fuel ethanol and other renewable fuels, which is a cleaner-burning replacement for petroleum-based diesel fuel, as well as meeting both the biomass-based diesel and overall advanced biofuel requirements of the Renewable Fuel Standard. The energy density of B100 (pure biodiesel) is significantly closer (compared to ethanol) to the density of its petroleum counterpart, but it is still roughly 8% less energy per gallon than petroleum diesel. The major drawbacks to biodiesel are: higher viscosity and density, higher freeze point, and a poor oxidative stability compared to petroleum diesel. These properties result in reduced cold weather performance and associated material compatibility concerns [8].

It is important to note that there is no usable first generation renewable kerosene. Kerosene is the primary component in jet fuel, and must have a very low freeze point in order to be operated within an airplane. Biodiesel's freeze point is significantly higher than acceptable, and will solidify if used in an airplane engine.

I.B.2. Second Generation Biofuels

The term 'second-generation' renewable fuels describes a broad classification of technologies which, in some ways, improve upon the first generation fuels. One way to classify these technologies is based on the type of feedstock being utilized for the fuel production. This classification includes cellulose-derived fuels, lignin-derived fuels, direct photosynthetic derivatives, lipid-derived fuels, and feedstock flexible bioconversion processes using multiple feedstocks [9]. For each of these classifications, only a few technologies have been invented with the capability to produce drop-in-compatible biofuels (DCB), whereas the others produce ethanol or other chemical substances that are uniquely different from their petroleum counterparts.

There is additional confusion surrounding these DCB fuels because many of the products classified as such are 'not quite compatible.' These fuels are identified as 'drop-in compatible' because they produce distillate/residue products that can be used at petroleum refineries and biorefineries, but are not engine ready. Also, some of these fuels need to be blended with petroleum analogs in order to be used in an engine. These types of processes produce drop-in compatible biofuel intermediates, while those producing engine-ready fuel products are classified as DCB [10]. These DCB processes produce fuels that are in compliance with all key specifications for existing petroleum-based fuels set forth by ASTM International [11-15] and other global standardization authorities.

Lipid-derived fuels include fatty acid based oils such as animal fats and waste cooking oils, as well as triglyceride based (TAG) oils such as crop oils, bacteriological oils, and algae lipids. The abundance and chemical organization of lipid-derived fatty acids (LDFA) make them an excellent starting material for the synthesis of renewable transportation fuels and chemicals. This is because LDFA are liquids with low oxygenation levels, making the conversion into fuels efficient. These oils also have negligible sulfur and metal content, which makes them an environmentally friendly alternative to petroleum-based fuels [9]. The work performed for this thesis focuses primarily on lipid-derived second generation biofuels, and in particular crop oils.

Triglyceride hydrotreatment is one form of technology that is currently capable of producing drop-in compatible biofuel intermediates with the potential of producing DCBs. During this process, TAG oils are deoxygenated into saturated hydrocarbons using a heterogeneous metal catalyst under high heat and hydrogen gas. This results in the complete deoxygenation of the feedstock into liquid hydrocarbon products. The problem with these products is that they have inferior cold-flow properties compared to their petroleum counterparts, and require blending or additional reactions to produce a quality fuel product. However, the cold-flow properties are superior to those of typical biodiesel products [10]. Honeywell/UOP has demonstrated processes to convert TAG oils into a drop in compatible jet fuel using paraffin isomerization following hydrotreatment.

These fuels were shown to have equivalent performance in fuel consumption, power output and emissions when compared to petroleum jet fuel [16].

The process of catalytic cracking TAG oils is another form of technology used to produce DCBs. This process is very similar to hydrotreatment, but with no hydrogen gas present. Without the use of high pressures of hydrogen, advanced cracking reactions can take place within the reactor resulting in products that can then be processed into DCB. The problem with the catalytic cracking process is that operation without hydrogen in most cases added technical challenges, such as increased catalyst deactivation and coking. The addition of steam to the catalytic cracking process can result in prolonged catalyst activity, as well as promoting dehydrogenation reactions, but the overall catalyst deactivation reduces the yield of salable products. This problem makes it difficult for the catalytic cracking process to provide a means to produce DCB [10].

One of the oldest methods of lipid conversion to DCBs is through the use of noncatalytic cracking. This process uses elevated temperatures and pressures to break the larger TAG molecule into smaller, fuel appropriate molecules in the absence of catalysts. Some of the first records of the noncatalytic cracking of TAG oils are in the early 1900s, and produced a variety of petroleum relevant compounds including paraffins, olefins, aromatics, and naphthalenes [10]. Until recently, TAG cracking processes have mostly been utilized to produce drop-in compatible fuel intermediates, but current technology allows for the production of DCB from TAG cracking.

Work through the University of North Dakota by Linnen et. al has shown that the fuel produced through the noncatalytic cracking process had acceptable heating values, densities, fire hazard, safety, cold weather performance, and corrosivity when compared to petroleum-derived fuels [10]. Additionally, this work showed that multiple TAG oil feedstocks can be converted into DCB, including canola oil, brassica oil, soybean oil, corn oil, cottonseed oil, camelina oil, linseed oil, and crambe oil [9]. Other work performed by Asomaning et. al has also shown the conversion of inedible lipid feedstock into renewable chemicals. These inedible feedstocks included beef tallow, yellow grease, brown grease, and cold pressed camelina oil [17].

Both sets of work also found that the feedstock's fatty acid composition did not significantly influence the organic liquid product yield. There were only minimal differences in the distribution of yields of jet fuel, diesel fuel, and naphtha. The main effect of differences between feedstocks was on the optimized operating temperature at which the cracking reactions take place [9, 17].

I.C. Economic Background

The designs evaluated in this thesis are specifically based on soybean oil. However, any triglyceride (TG) oil, unsaturated fatty acid, or carboxylic acid (e.g. lipids) can be used with minimal differences as noted in the previous section. Therefore, consideration for raw material prices was solely done regarding soybean oil. Crude oil prices were also evaluated so that a margin analysis with fuel values tied to crude oil prices could also be performed.

The main transportation fuels produced in the designs are: 1) naphtha, which is a gasoline blend stock, 2) kerosene, which is the primary compound of jet fuel, and 3) diesel oils. In addition to transportation fuel production, various other byproducts are produced, including: 1) butanes, 2) pentanes, 3) nonaromatic C6 raffinate, 4) C2-C11 fatty acids, 5) vacuum bottoms, and 6) mesophase pitch. Other potential by-products are introduced in Appendix B.

I.C.1. Raw Materials

I.C.1.i. Soybean Oil

The soybean oil market is closely tied to the soybean market, which has fluctuated greatly over the last ten years. Between the years of 2008-2010 the soybean oil market was the most sensitive. March, 2008 saw a crude soybean oil price of $1.50/kg, while in December, 2008, it was $0.66/kg [18]. This significant price drop was due to the low price of soybeans. This drop in soybean price was a reflection of a rebounding of the South American soybean crop, which was hurt the previous year by drought [19]. At the end of 2010, the price of soybean oil stabilized, and started to rebound from the crash in 2008, with the December 2010 price ending at $1.29/kg [18]. From 2010 on the price in soybean oil has steadily decreased from a high of $1.29/kg down to a low of $0.60/kg as of September, 2015. This steadily decreasing oil price follows the decline in soybean prices over this time, which is mostly due to ample global supplies, a strong U.S. dollar, and weakness in the currencies of other commodity producing and exporting countries [19].

Figure 1 shows the historic prices of soybean oil since November, 2009. The current spot price for soybean oil as of July, 2016 was $0.67/kg. The following designs are based off of a trended soybean oil price. This trend was performed using prices starting from January, 2011, and resulted in a trended soybean oil price of $0.60/kg.

Figure 1. Soybean oil price trend data [20].

I.C.1.ii. Crude Oil

The price of crude oil typically fluctuates significantly due to the underlying demand and supply curves, which are very inelastic. The inelasticity of the demand is due to long lead times for alternating the stock of fuel consuming equipment, and the supply is inelastic in the short term because it takes time to augment the productive capacity of oil fields. Over the past 15 years typical fluctuations were seen, as well as a significant spike in crude price (in the first half of 2008). Prices reached an all-time high of $131/barrel. This significant spike in price was mostly due to a significant decrease in non-OPEC supply, and an unprecedented surge in global demand, as well as multiple other small shocks seen within the oil industry. This all-time high, seen in the first half of 2008, was then followed by a significant decline in price in the second half of 2008. This decline was primarily due to the drop in demand for oil due to economic decline coupled with an increase in supply. Steady fluctuations and rises in prices were then seen from 2009 up until the middle of 2014 [21]. In June 2014, another sharp decline in prices occurred, with a low of $44/barrel. Since then, the price has stabilized with a more gradual decrease until February, 2016. Since February, the price has shifted toward an upward trend. Figure 2 shows these trends in detail. The current spot price for crude oil is $49/barrel, but trending the price since June 2015 gives a trended price of $34/barrel.

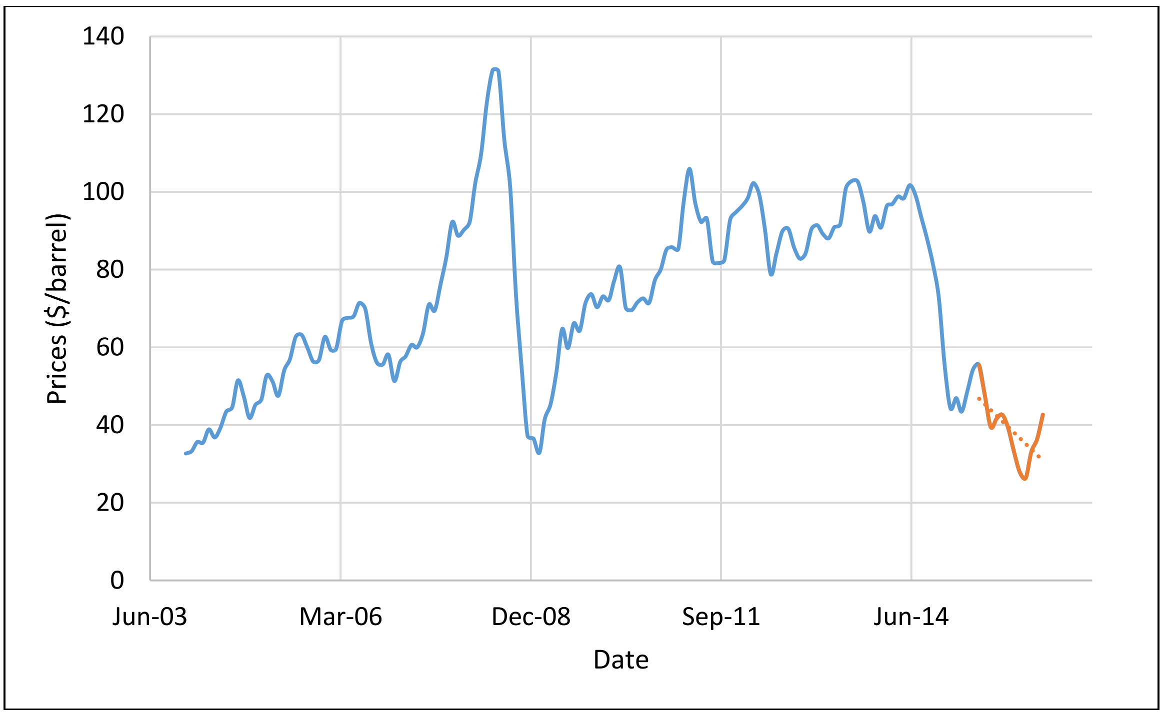


Figure 2. Crude oil price trends based on Midwest crude oil [22].

I.C.2. Products and Byproducts

I.C.2.i. Transportation Fuels

The transportation fuel products of petroleum naphtha, jet fuel (kerosene), and diesel fuel no. 2 closely follow the price trends of their typical raw material, crude oil. This can be seen in their price trends over the last ten years, with a spike in price quickly followed by a significant drop in the year 2008, as well as a steady incline in price from 2009-2010, with a steady decline in prices the following years.

Figure 3 displays the price trends of petroleum grade naphtha over the last 12 years. Based on this figure and prices found from an OPIS International Feedstock Report, the price of $0.36/L was used for petroleum naphtha prices [23]. Figure 4 shows the price trends of jet fuel A (kerosene) over the last 12 years. The current spot price for jet fuel was found to be $0.34/L, but trending the data since April 2011 results in a trended jet fuel price of $0.37/L [24]. Figure 5 presents the price trends for diesel fuel no. 2 over the last ten years. The current spot price for diesel no. 2 is $0.36/L, but using a trended price since April 2011 results in a price of $0.37/L [25].

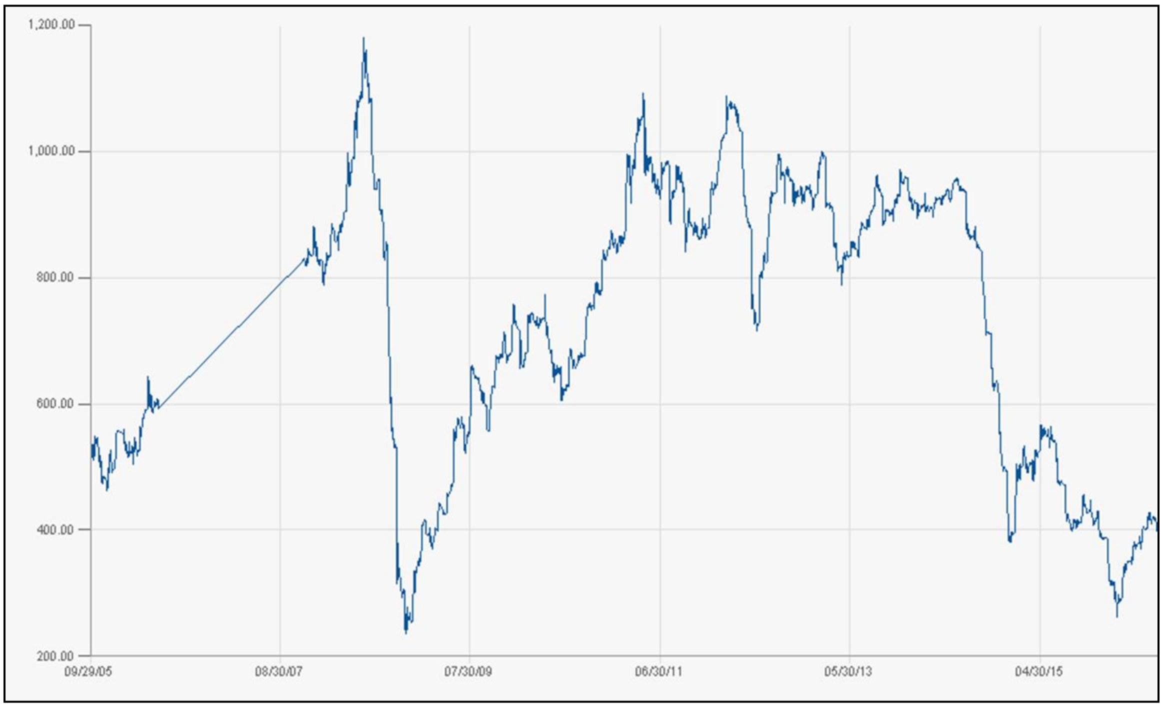


Figure 3. Petroleum naphtha price trends [26]. The y-axis displays the prices in dollars per ton, and the x-axis displays the date from October 2005-2016.

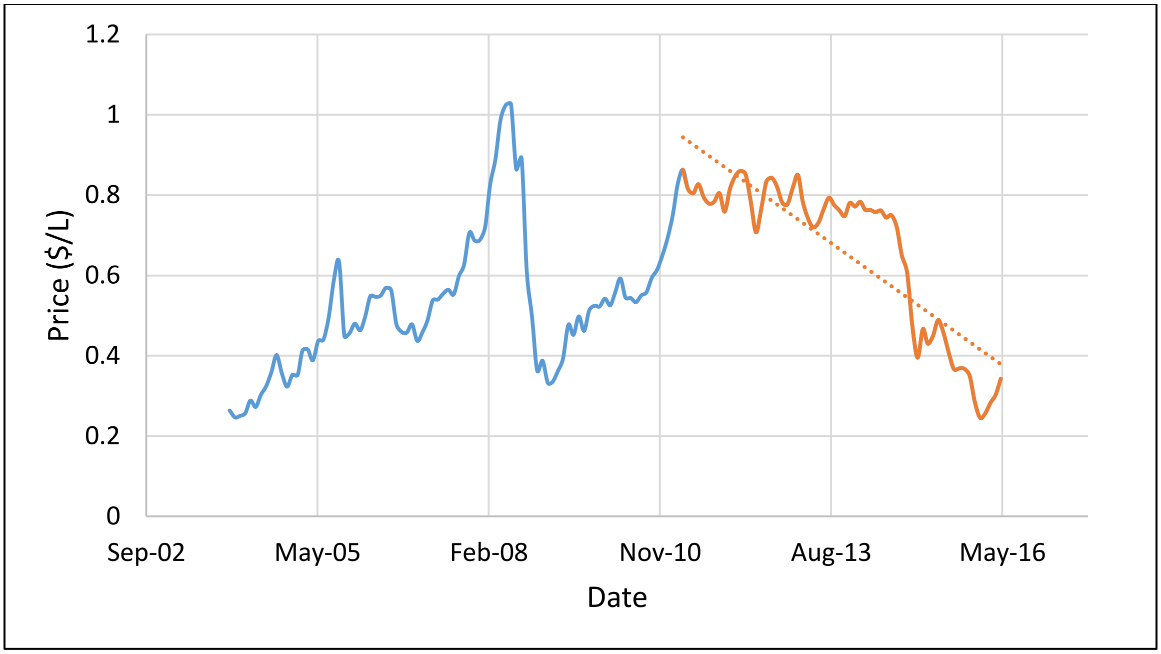


Figure 4. Jet fuel price trends [24].

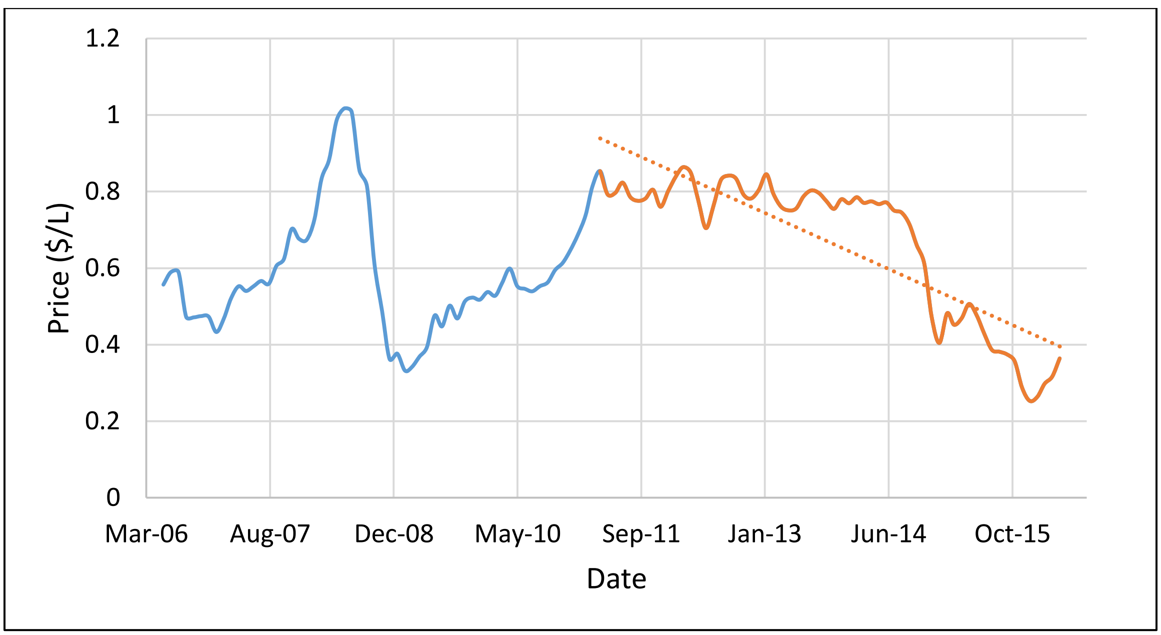


Figure 5. Diesel fuel no. 2 price trends [25].

I.C.2.ii. Byproducts

The remaining byproducts produced were all assigned spot prices based on quotes received from various companies. Table 1 provides the byproducts and sale prices used in this thesis.

Table 1. Byproduct sale prices [23, 27-32].

Byproduct	Price
Butane	$0.37/L
C5 Product	$36.61/bbl
Nonaromatic C6 Raffinate	$36.61/bbl
Vacuum Bottoms	$0.11/kg
Acetic Acid	$1.37/kg
Propionic Acid	$1.54/kg
Butyric Acid	$2.20/kg
Valeric Acid	$3.12/kg
Caprioc Acid	$4.39/kg
Heptanoic Acid	$3.61/kg
Octanoic Acid	$4.15/kg
Nananoic Acid	$13.56/kg
Decanoic Acid	$10.58/kg
Undecanoic Acid	$11.46/kg
Mesophase Pitch	$15.00/kg

I.D. Previous Experimental Work

The noncatalytic cracking process (NCP) is capable of transforming triglyceride-based oils (TAG) into renewable fuels and chemicals that are essentially the same as their petroleum counterparts through noncatalytic cracking and subsequent refinement. During noncatalytic cracking, the TAG is broken down under high temperatures and elevated pressures to yield an intermediate product that is a diverse organic mixture similar to petroleum crude oil. This cracked intermediate can then be refined into various fuels and organic byproducts using both reactive transformations and nonreactive chemical separations. All of the products produced are capable of meeting the current fuel specifications defined by the American Society for Testing and Materials (ASTM) for petrochemicals.

The NCP consists of four core subsystems used to convert triglyceride oils into petroleum equivalent renewable fuels: 1) non-catalytic cracking, 2) purification, 3) decarboxylation, and 4) trim purification. The non-catalytic cracking system is where the

TAG and/or fatty acid oils are cleaved into smaller molecules, with the majority of the molecules in the C5-C16 range. The molecules are then sent to purification. The light non-condensable (against room temperature water) gases and heavy ends are separated from the middle distillates in the purification section. The light gases and heavy ends are then sent to further processing and purification to produce usable and saleable byproducts (light end and heavy end purification) while the middle distillates are routed through decarboxylation reactors. Decarboxylation removes the carboxylic acid group that remain on some of the fatty acid fragments after cracking. Additionally, any alkenes are converted into their analog alkanes. Following decarboxylation, the fuel intermediates are sent to trim purification where the transportation fuel products are produced.

Over the past ten years, research has been conducted on each of the various subsystems needed to design a comprehensive facility capable of producing drop-in compatible renewable fuels and various byproducts in a variety of configurations using this technology. This research included determination of the optimized yields of organic liquid products (OLP) produced from the conversion of the inlet oil, which can then further be processed and separated into transportation fuels. A model that accurately represents the reactions completed by the noncatalytic cracking of the TAG oils was developed, as well as initial testing surrounding the byproduct production in both the light and heavy end processing, and fatty acid and aromatic byproduct production.

I.D.1. Triglyceride Cracking Research

I.D.1.i. Triglyceride Cracking Research

The model that represents the cracking reactions performed in the noncatalytic cracking reactor was taken from earlier research performed at the University of North

Dakota by Linnen et. al [10]. In this work Linnen found that the three C-O bond energies adjacent to the triglyceride backbone are the lowest energy bonds in the TAG molecules (Figure 6). It is important to note that these bond energies are nearly universal in all triglyceride molecules, so it is anticipated to have negligible dependence on the fatty acid feedstock [10]. In addition, he found that fragmentation of the C-O bonds will most likely result in the formation of carboxylic acids in the cracked product. A deeper analysis of the expected cracking reaction products can be found in Section III.F.4. of Linnen [10].

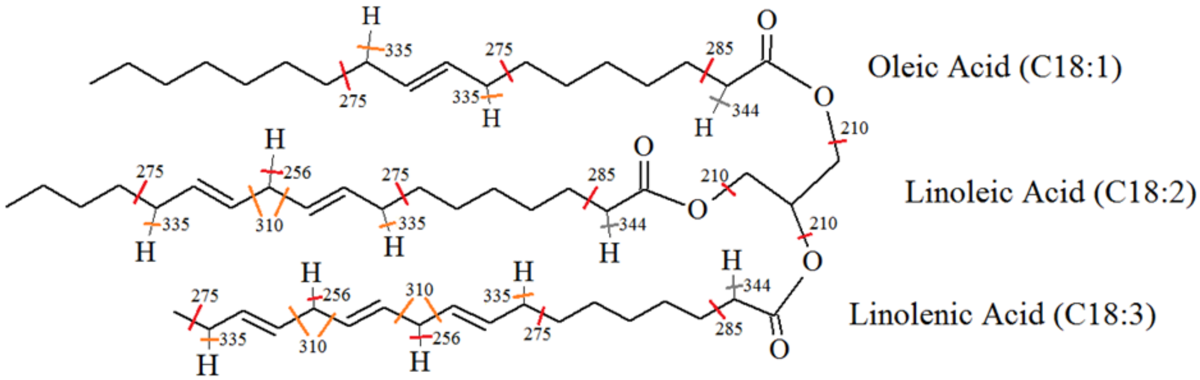


Figure 6. Triglyceride bond energies for glycerol –oleate, -linoleate, -linolenate [10].

Using the knowledge of the typical bond energies of triglyceride molecules, batch reaction experiments were then performed in order to develop rate constants for all of the possible noncatalytic cracking reactions. From this analysis, the potential products of triglyceride cracking were determined, which included acetic acid, heptanoic acid, undecenoic acid, and corresponding hydrocarbons of various lengths, such as tetradecane, hexadecane, undecene, nonane, and others [10].

Additional noncatalytic cracking batch reaction experiments were performed, and the liquid, gas, and coke products were analyzed to determine the compositions of the products. This produced sufficiently detailed composition data to interpret the effect of various operating parameters on the distribution and quality of products from the noncatalytic cracking process (NCP). Regressions were then performed on the compositional data in order to determine the effects of various reaction parameters on the distribution of functional groups in each fuel product. This regression, combined with the known bond energies associated with the TAG molecules and rate constants, was then used to develop the model of the NCP. A detailed analysis of the formation of the model can be found in Section VII.E.3 of Linnen et. al [10].

Once the model was developed, lab and pilot scale continuous experiments were conducted in order to determine the optimum operating conditions of the reactor to produce the greatest yield of transportation fuels while minimizing coke and gas formation. It was found that the optimal operating temperature should not exceed 440 °C in order to avoid coke formation. The optimal operating space time should not exceed 1.3 hours, because experiments conducted at this longer space time also produced more coke. See section VIII.B.4 of Linnen et. al for a deeper analysis on optimal reaction conditions [10].

Linnen also found that over the range of conditions tested, a greater cracking reaction temperature and space time were optimal for producing the greatest yields of lighter liquid fuels. Therefore, reaction conditions of close to 440 °C and 1.2 h space time should be used. The effect of pressure was found to be less influential on coke production and lighter fuel yields, so a lower pressure should be used in order to save on operational costs [10].

Using this knowledge, the output of the modeled TTCR was taken from Linnen's reactions using his H-soy experimental runs. This cracking reactor setup used a reaction temperature of 430 °C, a space time of 1.17 h, and a pressure of 1800 kPa. The representative ChemCad composition used for the designs can be found in Appendix J. It is also important to note that the TTCR developed for these reactions was a pilot scale reactor that is "industry ready." This allowed for the direct scale up of the design used by Linnen for the designs described in this thesis.

I.D.1.ii. Decarboxylation Research

In addition to developing the model used to represent the cracking reactions performed during noncatalytic cracking, Linnen also worked on the decarboxylation subsystem. Previous work done by Snare et. al had suggested that the ideal catalyst for deoxygenation was a 5 wt.% palladium supported on activated carbon (Pd/C5) [33]. The high cost of palladium catalysts makes it economically unattractive to use palladium-based catalysts for deoxygenation, and Linnen believed that nickel would be a suitable active component for catalyzed deoxygenation, as well as being available at greatly reduced costs relative to palladium. A detailed analysis of the experiments performed with nickel catalysts can be found in Sections V.C.1 and VI.A. of Linnen et. al [10].

From this work, it was found that nickel catalysts were capable of outperforming the palladium catalysts. In addition, the use of steam during the reaction was found to be necessary in order to prevent coking of the catalyst. The steam need only be provided in a 1:33 weight ratio of steam:distillates, even in the absence of hydrogen, in order to preserve the activity of the catalyst [10]. This steam also provided a hydrogen source that removed essentially all of the olefins from the cracking products. The ability to decarboxylate without hydrogen is a substantial advantage compared to other processes.

Taking the results presented by Linnen et. al, the decarboxylation reactors were designed to run with a 1:33 steam:distillate ratio, 300 °C, 2.2 Mpa, with the use of a basic Ni catalyst. Linnen's results were used to determine the outputs from the decarboxylation reactors based on the incoming feed. Linnen found that essentially all of the carboxylic acids were removed, producing an alkane one carbon length less than the inlet acid plus a mixture of CO and CO_2 molecules. Additionally, all the double bonds in these acids were hydrogenated.

The hydrogenation of the olefins occurs when the incoming steam reacts with some organic molecules, producing CO_2 and H_2 [10] via the shift reaction. This hydrogen is then used as the hydrogen source to remove double bonds found in the olefins. It was assumed that all of this hydrogen was consumed during the reaction. It was also assumed that the organics in the C20-C50 range were the only organics to be degraded by the steam, resulting in an abundance of methane and carbon dioxide. A 2% carbon degradation of alkanes in the C1-C10 range was also assumed.

Based on the previous work surrounding the decarboxylation subsystem, and resulting assumptions taken from this system, it would be beneficial for future work to be done surrounding this area. Extensive research regarding the Ni catalyst and steam usage, as well as a thorough analysis of the products should be done to ensure the assumptions made for this thesis are valid.

I.D.2. Light End Processing

Previous work surrounding the light end trim purification areas was performed by undergraduates at the University of North Dakota. This work provided the design of a world scale facility that processed natural gas into methane plus LPG [34]. This work is analogous to the light end trim purification area in the NCP of TAG oils into transportation fuels. Ideally, recovery of LPG from the syngas and heavier naphtha fuel range intermediates would be possible. The LPG report compared the use of cryogenic distillation to lean oil absorption as the means to separate out the LPG products from the natural gas.

The students found that in the cryogenic design, using three compressors to compress the incoming stream to 3.4 MPa, followed by expansion to 380 kPa would result in a natural gas stream of -140 °C. This stream then proceeded through distillation at the reduced temperatures. Reducing the stream down to this temperature then allowed methane and ethane to be separated from the LPG [34]. A thorough analysis of this method can be found in section 1.3 of this work.

Additionally, the group looked into lean oil absorption in order to separate out the methane and ethane from the LPG. They made use of the solvent Varsol as the lean oil capable of removing the LPG from the lighter components. Varsol is a commercial solvent with the following properties: MW=169 g/mol, Critical T = 382 °C, Critical P = 2.2 MPa, and SG = 0.78 [35]. The solvent was used in a lean oil absorber to remove the LPG and heavier components from the methane and ethane. Following lean oil absorption, the solvent was then removed from the LPG and recycled back through the absorber [34]. The entire analysis of lean oil absorption can be found in section A.2 of this report.

The report compared the two alternatives against each other to determine which is better suited for this particular process, and found that cryogenic distillation worked better than lean oil absorption.

I.D.3. Heavy End Processing

A high value carbonaceous material is any product that is essentially made up of elemental carbon, and typically consists of granular carbon products such as carbon black, coke, activated carbon, and carbon fibers. The processing of the TAG oil tars into valuable carbonaceous material has the potential to lower the risk surrounding the economics of a world scale TAG oil processing plant. Previous work at the University of North Dakota has looked into the production of green coke and carbon fibers from the tars produced during the noncatalytic cracking of TAG oils.

I.D.3.i. Green Coke Production

Nathan Bosquez worked on the conversion of crop oil tars into high grade carbon at the University of North Dakota. Bosquez et. al found that high value carbonaceous materials could successfully be produced from the heavy residual tars produced and recovered during the crop oil cracking process. He found that operating at a temperature of 460 °C or higher under atmospheric pressure resulted in the maximum formation of bio-derived coke, while minimizing the formation of low value gas products [36]. The coke he produced was the equivalent of green coke, which would need to be further processed using calcination in order to upgrade the coke to be used as high grade carbon.

The experimental results from the optimized coking conditions from Bosquez et. al are shown in Tables 2-5. Table 2 presents the solid, liquid, and gas distribution produced during the coking process. Table 3 shows the properties of the solid coke, while Table 4 shows the composition of the liquid portion produced. In addition, Table 5 presents the composition of the gas phase products.

Table 2. Mass balance for coking reactor experiments [36].

	Weight Percent (%)
Solid	10
Liquid	85.5
Gas	4.5

Table 3. Solid coke properties [36].

Property	**Value (wt. %)**
Moisture Content	0.1
Volatile Matter	30.52
Carbon Weight Percent	67.67
Ash Content	1.67

Table 4. Liquid portion analysis [36].

Fuel Cut	**Wt. % Carbon**
Lights (C1-C5)	0.6
Naphtha (C6-C8)	3.9
Jet Fuel (C9-C14)	4.3
Diesel Fuel (C15-C22)	55.6
Heavy Fuel Oil (C22-C30)	35.6

Table 5. Gas phase product compositions [36].

Component	Mole Percent (%)
H_2	5.88
CO	7.76
CH_4	20.87
CO_2	1.18
C_2H_4	2.19
C_2H_6	11.30
C_3H_6	3.48
C_3H_8	5.73
C_4H_X	4.89
C_5H_X	2.42
C_6H_X	0.96
C_7H_X	0.12
N_2	33.24

The actual compositions of all gas phase products were measured, so no model was needed to simulate these results. This was not the case for the liquid products. The relative amounts of each fuel cut were measured by Bosquez. From this information a model was developed that assumed that an equal amount of product for each carbon number in each fuel cut was produced. This included alkanes, alkenes, and cyclics. Bosquez also found that there were no aromatic compounds present post coking, and that roughly 4.5 wt% of the liquid product were fatty acids. This 4.5% was then equally divided amongst the C2-C10 fatty acids. It is important to note that the direct quantification of all liquid products should be performed for more accurate results.

The properties of the solid coke produced are similar to those of green coke. Green coke contains higher levels of volatile matter than calcined coke because of the lower temperatures used in its production. Bosquez found that the properties of this green coke could be upgraded through calcination to produce anode grade coke. Calcination of the green coke would produce a coke with a moisture content of 0.1 wt.%, volatile matter content of 0.25 wt.%, carbon weight of 99.35%, and an ash content of 0.3 wt.%. Most noteably there would be little, if any sulfur or heavy metal contaminants present in the coke. The complete presentation and analysis of Bosquez's results can be found in Chapter III of his work [36].

I.D.3.ii. Mesophase Pitch Production

Attempts to refine a high quality carbon fiber pitch from distillation residue are currently in progress at the University of North Dakota by Foerster et. al. Foerster is utilizing a prototype reactor for the production of mesophase pitch from the vacuum tars produced during the NCP process.

This prototype reactor is designed to convert isotropic pitch or tars into mesophase pitch. This is accomplished through the use of thermal processing under an applied shear force at vacuum pressure conditions. The reactor both quickly and efficiently removes volatile molecules while simultaneously facilitating the condensation of oligomers to produce a uniformly dispersed mesophase [10].

Based on the experimentation to date, Foerster has found that operating the pitching reactor between 400 and 415 °C and under a vacuum of 200-50 millitorr, can produce a high quality pitch. Approximately 35% of the tar being fed into the reactor leaves as pitch, while the remaining 65% comes off the top as a heavy byproduct. This heavy byproduct is similar in composition to fuel oil no. 5, and can be used as a fuel source in the boilers.

A full explanation of the methods and experimentation performed to test this product can be found in Foerster's dissertation, with an anticipated publication date of August, 2018.

I.D.4. Byproduct Production: Fatty Acid Recovery

Multiple sets of experimental work surrounding the recovery and sale of fatty acid byproducts from the noncatalytic cracking of TAG oils has been performed at the University of North Dakota. Initial work performed by Braegelmann et. al determined that the use of tertiary amines could substantially reduce the concentration of fatty acids in the cracking reactor outlet liquid through liquid-liquid extraction (LLE) [37]. Both DMEA and TMA tertiary amines were tested, but Braegelmann found that TMA was the preferred solvent because it is easier to regenerate since it forms fewer azeotropes with the fatty acids. The other advantage of TMA over DMEA was its high extraction efficiency [37].

Most research in the area of fatty acid LLE using tertiary amines involves extracting the acids from an aqueous solution. However, Braegelmann et. al investigated the use of TMA to remove the fatty acids from an organic mixture (the middle distillates). He found that the principles of fatty acid extraction from an aqueous mixture also apply to organic mixtures [37]. In addition, Braegelmann found that neither temperature nor pressure significantly affected the extraction process at the laboratory scale. A more complete analysis of the use of tertiary amines for fatty acid extraction can be found in Section 3 of this work.

Vosgerau et. al then took the information found by Braegelmann, and translated it to a continuous bench scale system [38]. Vosgerau also tested to see if it is possible to extract enough of the fatty acids from the middle distillate in order to achieve an acid number acceptable for JP-8 military grade jet fuel specifications (0.015). He found that with a single stage extraction, an acid number of 0.7 could be achieved [38]. Using this knowledge, it was assumed that through the use of multistage extraction this acid number could be reduced to the 0.015 specification needed. This means essentially all of the acids are removed from the middle distillates. In addition, Vosgerau found that neither temperature nor pressure affected the extraction process in the continuous system, so the extractor for the designs in this thesis are designated to operate at 25 °C and 103 kPa.

Vosgerau also looked for the optimal concentration of TMA in water, as well as the optimal TMA-to-process liquid ratio. It was found that a 25 wt% solution of TMA in water at a 0.0034 mole-to-gram ratio of TMA-to-process liquid removed the largest amount of fatty acids from the middle distillate. The full experimental design and analysis for Vosgerau's work can be found in Chapter II of his thesis [38].

Once the extraction step was defined, a system was needed to recover the fatty acids out of the solvent and to separate the individual fatty acids for sale. Previous undergraduate work through the University of North Dakota made an initial design of this process titled "Extraction and Recovery of Fatty Acids from Thermally Cracked Crop Oil" [39]. This work found that the best thermodynamic package to model the recovery of the acids in ChemCad 6.5.6 was either the UNIFAC or NRTL model [40]. Also, the design of the fatty acid recovery and purification train in this work provided significantly lower overall duties for condensers and reboilers compared to previous work, so this design was used for the current work. More information regarding the design of the fatty acid recovery and purification, as well as operating parameters can be found in Section 2 and Drawings 00-A-001, 00-A-002, and 0X-A-101 in this work [39].

When adapting the previous work [39], it was found that the initial design of the solvent recovery distillation columns performed in the simulator were unrealistic. Experimental results of Jones et. al, showed full recovery of all TMA and water from acetic and propionic acid. Jones also found that all of the acetic acid and heavier acids would be removed out the bottom of the column, while the TMA and water were removed out the top [41]. Using this information, a shortcut column was designed in order to provide realistic modeling. These shortcut columns were used in replace of the originally designed columns. More information regarding the recovery of the solvent from the extracted fatty acids can be found in Chapter II of Jones' work [41].

I.D.5. Byproduct Production: Aromatic Reformation

Linnen et. al found that roughly 10-20% of the OLP's from the noncatalytic cracking reactions are medium chain length (C_6-C_{12}) olefins [10]. These olefins are undesirable for fuel applications and must be converted prior to sale. They can either be deoxygenated, as described in Section I.D.1.ii, or they can be converted into a more valuable byproduct. Previous studies at the University of North Dakota researched the use of a catalytic reforming reaction to produce renewable aromatic hydrocarbons from these olefins.

Fegade et. al tested two different ZSM-5 catalysts having different SiO_2/Al_2O_3 ratios (CBV5524G and CBV 2314). He tested both catalysts over a temperature range of 300-432 °C, organic liquid product (OLP)-to-catalyst ratio from 4.5-15, and a reaction time of 5-20 min [42]. He found that higher temperatures resulted in significant increases in yield of all types of aromatics. These higher temperatures also encouraged the cracking of long chain molecules still present after the initial NCP step. It was also noted that an increase in aromatic yield was found as the OLP-to-catalyst ratio was decreased, and this also resulted in a lower coke yield. From these data, Fegade ascertained that the optimum operating conditions for the catalytic conversion of OLP into aromatics was a SiO_2/Al_2O_3 ratio of 23, a OLP-to-catalyst ratio of 4.5, reaction time of 12.5 min, and a temperature of 432 °C [42].

Using this information, a catalytic reforming reactor was designed to operate at the optimum conditions and high pressures. A model was then developed based on the data found by Fegade et. al, in order to model the reactions taking place within the reactor for a given feed. These assumptions for the model included a 5 wt% yield of coke, 81 wt% yield of liquid products, and a 14 wt% yield of gaseous products. The following table (Table 6) shows the composition of the gaseous products from the reactor. The production of carbon monoxide and carbon dioxide is consistent with the decarboxylation of oxygenated compounds, which reacted completely [42].

Table 6. Composition of gas fraction obtained from OLP reforming [42].

Gas	Volume %
Carbon Monoxide	2.8
Methane	6.4
Carbon Dioxide	1.5
Ethane	0.28
Ethylene	13
Propylene	54
Butane	16
Butene	2.1
Pentane	0.57
Hexane	0.58
Hydrogen	2.8

In addition, Table 7 shows the ratio of products in the liquid phase that was used to develop the model. As can be seen, essentially all of the olefins and carboxylic acids are converted during the reforming step, which is important for high quality transportation fuels. Also, Fegade et. al found that the carboxylic acids within the incoming OLP were converted to the same size alkanes, the C_5-C_6 alkanes were all reformed into aromatics, and the larger sized C_{17} and higher alkanes were cracked into smaller sizes [42]. Surprisingly, roughly 75% of the mono-aromatics were C3-, C4- and C5-substituted benzenes, while only a small fraction were C1- and C2-substituted benzenes.

Table 7. Chemical composition of the liquid reformate [42].

Products	Weight %
Alkane	21
Alkenes	0.6
Dienes	1.3
Cyclic	13
Ketones	ND*
BTEX	8.9
Mono-aromatics	39
Indanes	4.9
Naphthalenes	7.3
Carboxylic Acids	ND*
Unidentified	6.5

Note * ND=Not detected, i.e., below the limit of detection

The above information was compiled together to model the reforming reactions on a large scale. The data in its entirety can be found in Chapter V of Fegade et. al [42].

In addition to the reforming step, the byproducts produced during the reforming reactions need to be separated from the transportation fuel intermediates. Previous work at the University of North Dakota tested solvent extraction of aromatics, and developed simulations through ChemCad 6.5.6 that separated out the individual aromatic products. N. Khatibi performed solvent extractions using sulfolane, and found that the optimum solvent extraction conditions would be a temperature of 50 °C, and a solvent-to-aromatic ratio of 9. The testing used single stage extraction, and achieved up to 70% efficiency. This single stage extraction data was then used to estimate the efficiency of a multiple stage extraction, which was found to achieve up to 99.5% efficiency. A thorough analysis of this experimental procedure and data can be found in Section 3.3 of this work [43].

In addition to developing a solvent capable of extracting the aromatics from the OLP, simulations were also performed to model the separation of the solvent from the aromatics, and separate the aromatics individually. Three different configurations were modeled, but the most efficient scheme involves a distillation train of four distillation columns. In this scheme the first column separates the aromatic hydrocarbons from the sulfolane, allowing the sulfolane to be recycled back to the extractor. In the second column benzene is recovered as the light key to a purity of 99.2%. The third column separates toluene as the light key to a purity of 99.0%, and the last column separates the o-and p-xylenes from the m-xylene and ethylbenzene. These simulation results obtained were used as a starting point for designing distillation trains capable of separating the catalytic reforming products, which are larger molecular weight aromatics. These columns will need to be further developed and refined for the work performed in this thesis. Section 3.4 of this study provides a full explanation of these experimental results [43].

Chapter II

SCOPE OF WORK

The work performed for this thesis follows the method used to produce a scoping study for the process industries. Scoping studies have two main parts, the preliminary design, and the economic assessment. The following sections describe how these parts were produced for this work.

Section II.A describes the method followed for producing the preliminary design of each alternative, while Section II.B reviews the production specifications required for drop in ready renewable transportation fuels. Section II.C analyzes the procedure used to produce the economic assessment on each alternative and Section II.D examines the different alternatives that are developed and evaluated in this thesis.

II.A. Preliminary Design

The objective of a preliminary design is to develop processes that can satisfy the recognized opportunity. This level of design includes heat and material balances, identification and preliminary approximate sizing of major equipment pieces, and development of input/output diagrams, block flow diagrams, and process flow diagrams on all alternatives produced. Input/Output diagrams are used to help define the scope of the opportunity. Block flow diagrams help the preliminary preparation process, as well as display the material balances. Process flow diagrams show all unit operations with their approximate size specifications, show the material balances, and includes the temperature and pressure profiles [44, 45]. A process simulator is usually used to develop the process flow diagrams for each alternative. For this work the process simulator ChemCad 6.5.6 was used. This program, developed by Chemstations, provides an integrated suite of intuitive chemical process engineering software [40].

The preliminary designs for the process alternatives of noncatalytically cracking TAG oils into transportation biofuels were created using previously developed inhouse fundamental data and literature available surrounding the topic. These data, presented in Chapter 1, were then used to develop process simulations.

First, input/output diagrams and block flow diagrams were produced for each alternative. The input/output diagrams depict the overall mass balance for the entire process, and illustrate the inputs and outputs to the system. The block flow diagrams show all major separation and reaction steps required, as well as mass balances. Following the production of these drawings, the process simulator was used to develop the process flow diagrams and to optimize and size all major pieces of equipment. The ChemCad simulations for the processes can be found in Appendix H.

All distillation columns found in each alternative were designed through the use of the process simulators. They were optimized to have the optimum balance of overall energy use vs. column height. The feed tray was located to obtain the column with the lowest duty, while keeping the reflux ratios reasonable. The number of trays required for each column were then chosen based on the above criteria. These optimizations can be found in Appendix E. The distillation columns were then sized using Separations Process Engineering [46]. The tray efficiencies were assumed to be 0.7, with a flooding fraction of 0.8, and a vapor flow of 0.9. The trays were assumed to have a tray space of 12-24 inches depending upon the service and height of the column. A column diameter's worth of length was added to the height of the columns to allow for bottom liquid holdup, which produces enough head to push the bottoms through the thermosiphon reboiler. An additional column diameter's worth of height was added to the top of the column as well to account for vapor-liquid disengagement. The reflux drums for each column were designed to have a five minute liquid residence time at 50% volume. They are horizontal in orientation, with a length to diameter ratio of 4 [47]. All sizes were rounded up to the nearest half meter.

The flash drums were designed using process simulations, and were then sized based on a height to diameter ratio of 4. The surge volume of liquid in the drums was sized large enough, to have a five minute residence time at 50% volume [46]. The three phase separators were designed as horizontal drums, and all other flash drums were designed vertically.

The heat exchangers were designed using typical "U" values, and it was assumed that condensing occurs on the shell side. Steam was sent through the tubes if it is not condensing. The values for the overall heat transfer coefficients were found from the Chemical Engineers' Handbook, fifth edition, and the enthalpies of the steam and water used in the exchangers were found from the Introduction to Chemical Engineering Thermodynamics [48, 49]. If cooling water was used it was assumed to be available at 30 °C and returned at the approach temperature [47]. Three types of steam were used throughout the process, medium pressure steam at 239 °C and 3.2 MPa, high pressure steam at 400 °C and 4.5 MPa, and superheated steam at 435 °C and 6 MPa. The processes were designed to produce the majority of the superheated steam and all of the medium pressure steam onsite in the same boiler with different tube banks. The remaining superheated steam and high pressure steam are produced in another boiler with two separate tube banks.

Compressors were sized through ChemCad simulations, and were assumed to have a polyentropic efficiency of 55%. A maximum compression ratio of 4 was assumed when dealing with staged compression. Pumps were also sized through ChemCad, and were assumed to have an efficiency of 65%. When sizing the knockout drums, it was assumed the velocity of the gas was 21 m/s before the drum, and is reduced to 2 m/s within the drum. They were also sized to have a diameter to height ratio of 3-5 depending on the pressure [47].

The turbulent tubular cracking reactor (TTCR) was designed based on experimental data found from Advanced Reactors and Novel Reactions for the Conversion of Triglyceride Based Oils into High Quality Renewable Transportation Fuels [10]. The required reactor could be directly scaled up from the pilot scale reactor used for those experiments. It was designed to have a residence time of 1.17 hr, and scaled up to have 20,582 tubes at 24 meters in length. In order to develop the superheated steam needed to heat the reactor, the log mean temperature difference could be no larger than 13 °C to avoid coking due to hot spots in the reactor.

The decarboxylation reactors were also scaled up from this dissertation [10] in the same manner. Based on the experimental data, all the carboxylic acids are removed within the decarboxylation reactor. The product from this is carbon dioxide. It was also found that essentially all of the double bonds are removed due to the reaction with the incoming process steam. These alkenes undergo hydrogenation, and the result is the alkane with the same carbon number.

The syngas produced in the processes was designed to be used as boiler feed. The flame temperature was calculated from the stream to ensure it would be able to heat the boiler feed water to the required temperature of the superheated steam. From there, the boiler was designed to have a duty capable to heat all the required superheated steam for the process.

Sample calculations for all equipment sizing can be found in Appendix D.

In addition to the drawings and equipment sizing, a process description, raw materials list, products list, utility requirements list, chemicals and catalysts list, and a major equipment list were developed for each alternative.

II.B. Product Specifications

Before the transportation fuels and byproducts can be sold they need to first be checked to ensure they meet all the product specifications. All fuel products need to comply with the relevant ASTM standards, and fatty acid products need a purity of at least 98%.

The ASTM standards for the products contain a list of physical measurements that each fuel must meet before it can be sold as a fuel product. Some of these properties cannot be estimated using a simulator (corrosion, residual matter, etc.), and were assumed to be met as long as all other measurements capable of being estimated through the simulation were met. Some of the property estimates not available in ChemCad, were estimated using Aspen V8.6. Therefore, both process simulators were used to ensure the products met as many of the ASTM specifications as could be estimated. The assumption that the specifications that couldn't be estimated were within specification was determined to be valid in previous experimental work.

Tables 8-13 display the fuel properties that could be estimated through simulations. These were used to determine if the products met the required ASTM standards.

Table 8. LPG and butane specifications based on ASTM 1835 [11].

Specification	**LPG**	**Butane**
Vapor pressure at 37.8 °C, max (kPa)	1167-1880(density at 15 °C)	485 kPa
Evaporated temperature, 95% max (°C)	2.2	2.2
Pentane and heavier, max (vol%)	2.0	2.0
Relative density at 15.6/15.6°C	Report	Report
Free water content	None	None

Table 9. Petroleum naphtha specification based on ASTM 4052, 4294, and 5134 [50].

Specification	**Naphtha**
Density at 15 °C, max (kg/m3)	700
Total paraffins, max (vol %)	60-65
Olefins, max (vol%)	1.0
Aromatics, max (vol%)	10-12
Initial boiling point (°C)	Report
Temperature at 5% recovered (°C)	Report
Temperature at 10% recovered (°C)	Report
Temperature at 20% recovered (°C)	Report
Temperature at 30% recovered (°C)	Report
Temperature at 40% recovered (°C)	Report
Temperature at 50% recovered (°C)	Report
Temperature at 60% recovered (°C)	Report
Temperature at 70% recovered (°C)	Report
Temperature at 80% recovered (°C)	Report
Temperature at 90% recovered (°C)	Report
Final boiling point (°C)	130
Reid vapor pressure at 37.8 °C, max (kPa)	480

Table 10. VM&P naphtha specifications based on ASTM 3735 [15].

Specification	**VM&P Naphtha**
Aromatics, max (vol%)	20
Initial boiling point, min (°C)	113
50% recovered, max (°C)	135
Dry point, max (°C)	154
Flash point, min (°C)	4
Specific gravity at 15.6 °C, min	0.715
Specific gravity at 15.6 °C, max	0.792

Table 11. Jet fuel specifications based on ASTM 1655 [13].

Specification	Jet Fuel A
Aromatics, max (vol%)	25
10% recovered, max (°C)	205
50% recovered (°C)	Report
90% recovered (°C)	Report
Final boiling point, max (°C)	300
Flash point, min (°C)	38
Density at 15 °C (kg/m3)	775-840
Freezing point, max (°C)	-40
Viscosity at -20 °C, max (mm2/s)	8.0
Net heat of combustion, min (MJ/kg)	42.8
Smoke point, min (mm)	25
Cetane number (min)	40

Table 12. Diesel fuel oils specifications based on ASTM 975 [12].

Specification	Diesel Fuel no. 2
Flash point, min (°C)	52
90% recovered, min (°C)	282
90% recovered, max (°C)	338
Kinematic viscosity at 40 °C, min (mm2/s)	1.9
Kinematic viscosity at 40 °C, max (mm2/s)	4.1
Cetane number, min	40
Cloud point (°C)	Report

Table 13. Fuel oils specifications based on ASTM 396 [14].

Specification	Fuel Oil no. 4	Fuel Oil no. 5	Fuel Oil no. 6
Flash point, min (°C)	55	55	60
10% recovered, max (vol%)	Report	Report	Report
90% recovered, min (vol%)	Report	Report	Report
90% recovered, max (vol%)	Report	Report	Report
Kinematic Viscosity at 40°C, min (mm2/s)	5.5	N/A	N/A
Kinematic Viscosity at 40°C, max (mm2/s)	24.0	N/A	N/A
Kinematic Viscosity at 100°C, min (mm2/s)	N/A	5.0	15.0
Kinematic Viscosity at 100°C, max (mm2/s)	N/A	8.9	50.0
Pour point, max (°C)	-6	N/A	N/A

II.C. Economic Assessment

Following the completion of the process drawings, a broad cost estimate and economic assessment were performed. These components of the scoping study are then used to determine if the process alterative is worthwhile. This economic assessment is reported at a ±40% confidence, and is used to assess the attractiveness of a project and its alternatives. This estimate is based upon the design found in the process flow diagrams [51].

First, a capital cost summary for the processes was produced. The total costs were estimated using the factored estimate method proposed by Guthrie and fully developed by Ulrich [47]. This method uses the purchased equipment cost of each piece of equipment to estimate the overall total capital investment of the project. Budgetary quotes were obtained for the most expensive pieces of equipment: TTCR, decarboxylation reactors, extractors, compressors, boilers, refrigeration systems, and distillation column trays. All communication between contacts can be found in the communication records in Appendix G. All remaining pieces of equipment were priced based on the cost charts found in Ulrich [47]. Prices were adjusted from the 2004 date of the textbook to April 2016 using the CECPI index from Chemical Engineering magazine [52].

The equipment prices were multiplied by a unit operation-specific factor, the bare module factor, to obtain the module cost. This factor accounts for the installation expenses of the unit operation [47]. The sum of all the module costs provides the total bare module cost of the investment. An additional 18% of the total module cost is added to account for contingency and fees associated with the process. This value equates to the total module cost (C_{TM}). Twenty percent of the C_{TM} is added to cover auxiliary facilities. Typically 30% of the C_{TM} is added to cover the auxiliary facilities, but the pricing of installation and procurement of the boiler and refrigeration unit are included within the broad cost estimate. The reduction from 30 to 20% was found from the auxiliary facility breakdown found in Ulrich [47]. The resulting value is the fixed capital investment for the (FCI) process. Fifteen percent of the FCI is added to account for working capital. The initial charge for the consumable chemicals and catalysts is then added to yield the total capital investment (TCI) for the process [51].

The total operating costs for the process were also estimated. These consist of raw material costs and manufacturing costs. The manufacturing costs include chemicals and catalysts, operating labor, maintenance costs, and utilities. The process is assumed to have an operating factor of 95%. Intermediate results for the operating costs can be found in Appendix C.

To find the price of chemicals and catalysts required for the processes, it was assumed that there will be a yearly depletion of 4% of the catalyst required for decarboxylation that must be replenished, and that it needs to be fully recharged every four years. Also, a 17% yearly depletion of any solvents used for the processes must be replenished [51].

The operating labor for each process is based on a continuous 24 hour, 7 days a week operation for the plant. Four and a half shifts cover this continuous operation. The total number of operators needed to maintain 24/7 operation is based on rules of thumb [51]. These rules of thumb are based on the number of major and minor unit operations associated with the process. The operating labor expense was found from the Job Service North Dakota website. The salary used was based off of a chemical processing operator salary [53]. Fifteen percent of the total operating labor expense is added to account for supervisor costs.

Maintenance costs were calculated as 6% of the fixed capital investment, and the prices for the required utilities were calculated through heuristics developed by Turton et. al. [54].

Revenues generated for each process were calculated based off of the trended prices shown in Chapter 1. If no price trends were found, the price were based off of a price quote obtained for the product. These quotes can be found in Appendix G.

The taxes were calculated based on a 35% federal income tax rate and a Minnesota state income tax rate of 9.8% [55]. A blended federal and state tax rate of 41% was used as described in Appendix C. The taxes were calculated from the gross profit of the process. The taxable income was calculated using a 17 year MACRS tax depreciation schedule using the whole year accounting method. This calculation can also be found in Appendix D.

The cash flow sheet for each process displays all factors affecting the profitability of the process. The fixed capital investment was spread out over the established two years of the project, running from year -1 to year 0. This duration reflects the total time required for design, procurement, and installation. At year 0, the working capital plus initial charge of chemicals and catalysts are added to the nontaxable charges. The working capital is recovered in year 20. From these calculates the net present value (NPV) at a hurdle rate of 12% was calculated for the project over a 20 year lifecycle to determine the overall profitability of the process. Also, the discounted cash flow rate of return (DCFROR), which is an indicator of efficiency of an investment, was calculated.

II.D. Alternatives

Multiple process alternatives were considered to noncatalytically crack TAG oils into transportation biofuels in order to determine the most economically viable process. A comparison of the alternatives is presented in Chapter VI in order to assess if the development of a world scale plant processing TAG oils into transportation fuels is economically feasible. Three of the alternatives have been developed with a preliminary design and economic assessment, as described above. These alternatives produce saleable byproducts with the goal of reducing the risk surrounding the economics of producing transportation fuels from triglyceride based oils at the expense of additional capital cost and facility complexity.

Chapter III describes the base design of the TAG oil processing plant. In this design soybean oil is converted into three transportation fuels, petroleum naphtha, jet fuel and diesel fuel no. 2, through noncatalytic cracking and decarboxylation. The byproducts of butane, acetic acid, and vacuum bottoms are also produced for sale.

Chapter IV describes a biorefinery design that includes C2-C11 fatty acid recovery through liquid-liquid extraction. Once recovered, the remaining cracked soybean oil will be decarboxylated, and these transportation fuels: petroleum naphtha, jet fuel and diesel fuel no. 2, will be recovered. The byproducts of butane and vacuum bottoms are also recovered in this process.

The design shown in Chapter V processes the vacuum bottoms into mesophase pitch as a saleable byproduct. This pitch is a feedstock for the production of continuous carbon fibers. The main transportation fuel products, petroleum naphtha, jet fuel and diesel fuel no. 2, are still produced, as well as the byproduct of butane.

Appendix A reviews an alternative design for the base design of a biorefinery. This alternative produces the additional byproducts of C5 product and C6 nonaromatic raffinate. These additional byproducts lessen the production of transportation fuels, which is why this was deteremined to be an alternative to the base design.

Appendix B presents other under developed alternatives. These include other heavy end processing designs, light end processing designs that recover LPG as a saleable byproduct instead of butane, and aromatic reformation. These alternatives were deemed to be either unfeasible or unlikely to be economically profitable, and for these reasons they were not fully developed like the other alternatives.

CHAPTER III

A BIOREFINERY BASED ON THE NONCATALYTIC CRACKING OF TRIGLYCERIDE OILS – BASE DESIGN

The base design for a biorefinery based on the noncatalytic cracking of TAG oils includes the production of transportation fuels and limited byproducts without the production of any additional byproducts that reduce the quantity of fuel products. This biorefinery is designed as a world scale processing plant capable of producing renewable transportation fuels, and hopefully help to lower the dependence upon petroleum-based transportation fuels.

The following sections describe the process used to develop a preliminary design and economic assessment for the base design of a biorefinery based on the noncatalytic cracking of triglyceride oils. Section III.A reviews the preliminary design of the biorefinery, Section III.B describes the economic assessment performed based on this design, and Section III.C examines the profitability of the process and describes possible ways to increase its profitability.

III.A. Process Design

The design provided is specifically based on a feed of soybean oil. However, any triglyceride (TG) oil, unsaturated fatty acid, or carboxylic acid (e.g. lipids) can be used. Differences in the product rates and slight differences in the reaction temperatures are the only expected variations based on feedstock. A 7500 MTPD soybean oil extraction plant can efficiently produce 600,000 m^3/year of crude soybean oil [56]. The typical composition of this soybean oil can be found in Table 14. The crude soybean oil feed, shown in Table 15, can then be noncatalytically cracked into naphtha which is a gasoline blend compound, plus transportation fuel quality kerosene and diesel oils. Kerosene is the primary compound of jet fuel. The flow rates of the most significant products can be found in Table 16. All products produced are in compliance with the fuel ASTM standards. The properties of these streams can be found in Tables 17-19. Other possibilities, not directly addressed in this design are other kerosene products and diesel no. 1.

In addition to the production of transportation fuels, the byproducts of butane, vacuum bottoms, and acetic acid are produced. The flow rates of all byproducts can be found in Table 20, and the ASTM properties of butane can be found in Table 21. This process also produces two streams that are used as boiler feed for the plant. These streams can be found in Table 22. The input/output diagram (drawing 00-A-022) shows the overall mass balance and mass flow rates of the inputs and outputs to the process.

Catalyst is used in the decarboxylation reactions, and is used to convert the carboxylic acids that are produced during the noncatalytic cracking of the soybean oil into alkanes. The amount of catalyst used for the process can be found in Table 23, and the utilities required are presented in Table 24.

The process was designed as four core subsystems. The first subsystem consists of the thermal cracking section. In this section the incoming soybean oil is cracked into a three phase product through the use of noncatlytic cracking at high temperatures. The majority of the molecules are cracked into the C5-C16 range. The next subsystem is the purification section. In this section the light ends and heavy ends are separated from the middle distillates, which are known as organic liquid product (OLP). The OLP is then sent through the next subsection, decarboxylation. In this area the carboxylic acids are converted into hydrocarbons and the alkenes are hydrogenated into alkanes through the use of steam. Following decarboxylation, the OLP's are sent to the final subsystem, trim purification. In this section the OLP's are purified into transportation fuel products, and the light ends and heavy ends are purified into saleable byproducts.

All separation and reaction unit operations that are required for the process are shown in the quantitative block flow diagram (BFD). This drawing also shows the mass balance for the individual process areas. The thermal cracking and purification subsections are shown on Drawing 00-A-023/sheet 1, and the decarboxylation and trim purification subsections are shown on sheets 2-4.

Drawings 0X-A-024/X show the process flow diagrams for the process. The following detailed process description is based off of the process flow diagrams. Table 25 displays the equipment lettering system, Table 26 shows the equipment number codes, and Table 27 presents an example equipment number scheme. These tables explain how the equipment in Tables 28-35 were coded. Table I.6 in Appendix I shows examples of all the equipment used in the drawings. Table 36 shows the drawing number codes, and Table 37 displays an example of how the drawings are named.

III.A.1. Thermal Cracking Section (Drawings 01-A-024/X)

TG oil is assumed to enter the process from storage at 1000 kg/min, a temperature of 20 °C, and a pressure of 140 kPa (stream 1). In order to heat the incoming oil to the desired temperature (410 °C) it is first sent through the post cracking cooler (E-201 A/B). This heat exchanger uses the excess heat of the products coming out of the TTCR (R-

101) in stream 11 to preheat the feed. E-201 A/B heats the oil to 310 °C, and then it is pressurized to the reaction pressure of 1930 kPa by L-101 A/B. Following the pre-cracking pump, the oil is heated to the desired temperature of 410 °C in E-502 A/B. The soybean oil then enters the TTCR (R-101) in Stream 8 on Drawing 01-A-024/2 at 410 °C and 1900 kPa.

The Turbulent Tubular Cracking Reactor is used to noncatalytically crack the TG oil into transportation fuel intermediates. The majority of these molecules are in the C5-C16 carbon number range. This reactor was designed to be 6.1 m in diameter and 12.2 m in length with 10300 tubes. It operates at a temperature of 430 °C and 1800 kPa, and has a residence time of 1.17 hr. The soybean oil and crackate flow through the tube side of the reactor, and the superheated steam (435 °C and 6000 kPa) that heats the reactor flows through the shell side. The products leaving the reactor are used to heat the incoming soybean oil in E-101 A/B, and are then sent to the purification section of the plant in Stream 12 at 1000 kg/min, 230 °C, and 1760 kPa.

III.A.2. Purification Section (Drawings 02-A-024/X)

Following the thermal cracking section of the plant is the purification section. In this section the middle distillates are separated from the light and heavy ends, and the fatty acids are removed from the middle distillates. First, the cooled TTCR products (Stream 12) are sent to the acetic acid separator 1 (D-107). In this flash drum the majority of the C1-C8 carbon length molecules (Stream 17) are flashed off of the remaining C7-C50 molecules by flashing the incoming stream to 1380 kPa. In addition to the removal of the lighter compounds, some of the acetic acid that is produced in the TTCR separates out from the organic phase. This aqueous acetic acid, with small amounts of propionic acid, are removed from the organic liquid product in Stream 15. The organic liquid is then flashed again in D-101 at 690 kPa. In this flash drum the remaining lighter molecules are removed in Stream 19, leaving the liquid products in Stream 18. Streams 17 and 19 are then sent to D-108 on Drawing 02-A-024/3, and Stream 18 is sent to E-202 A/B on Drawing 02-A-024/2.

Stream 18 is first cooled to 150 °C in E-202 A/B, and is then flashed a third time in D-102. This flash drum operates at 140 kPa. The liquid products are then sent to the atmospheric distillation column on Drawing 02-A-024/4 in Stream 23. The gas products from D-102 are first compressed by G-101 A/B to 410 kPa, and are then sent to D-108 on Drawing 02-A-024/3 in Stream 25.

Streams 17 and 19 from sheet 1 are sent into acetic flash drum 2 on Drawing 02-A-024/3. Stream 25 from G-101 on sheet 2 is also sent into this flash drum. D-108 removes the light ends in the C1-C6 carbon range in the gas product in Stream 56. The remaining C6-C8 organic liquid is removed in Stream 57. D-108 also has a small amount of acetic and propionic acid, which separate out from the organic liquid phase into an aqueous phase. This product (Stream 58) is combined with Stream 15 in D-310 to form Stream 72, the acetic acid byproduct stream at 5 kg/min. From D-108, stream 56 is sent to D-105 on Drawing 05-A-024/1 for light end purification. Stream 57, the C6-C8 organic liquid, is sent to combine with the tops from the atmospheric distillation column (D-201) as shown on Drawing 03-A-024/1.

The atmospheric distillation column (D-201), shown on Drawing 02-A-024/4, separates the naphtha/kerosene range fuel intermediates from the heavier diesel fuel range intermediates. D-201 splits the incoming Stream 23 at the C12-C13 carbon range.

The distillate products (C7-C12) leave the top of the column at 210 °C and 124 kPa. They are first condensed at 60 °C in E-101 A/B and pressurized to 140 kPa by L-104 A/B prior to combining with Stream 57 on Drawing 03-A-024/1. The bottoms from D-201 exit the column at 280 °C and 140 kPa. They are then heated to 310 °C in E-401 A/B and are then sent to vacuum distillation column D-202 as Stream 33 at 590 kg/min. D-201 is 8.4 m tall, 2.4 m in diameter, and has 7 trays. The feed enters the column at tray 3, and the column operates with a reflux ratio of 0.1.

Stream 33 enters the vacuum column (D-202) on Drawing 02-A-024/5 at tray 5. D-202 operates at 30 kPa, and has a height of 20 m, diameter of 2.9 m, and 20 trays. D-202 separates the diesel range fuel intermediates from the heavy end byproducts. This separation occurs at the C30 range, with the diesel fuel intermediates leaving in the distillate (C12-C30), and the heavy ends leaving the bottom (C30-C50). The distillate leaves D-202 at 315 °C and 21 kPa. It is then cooled to 230 °C in E-102 A/B. The reflux is then sent back to the column at a reflux ratio of 1.3, and the distillates head to decarboxylation in R-102 at 230 °C, 140 kPa and 320 kg/min in Stream 49. The bottoms exit D-202 at 330 °C and 35 kPa. They are then heated to 340 °C in E-402 A/B, and the Vacuum Bottoms (Stream 41) byproduct is pressurized to 140 kPa by L-130 A/B before being sold at a rate of 280 kg/min.

III.A.3. Decarboxylation Section (Drawings 03-A-024/X)

Stream 57 from D-108 on Drawing 02-A-024/3 and Stream 29 from L-104 A/B on Drawing 02-A-024/4 combine to form Stream 59 (220 kg/min) prior to being sent through the naphtha decarboxylation reactor (R-102 A/B). These streams combine to 60 °C and 140 kPa, and are then pressurized to 2400 kPa by L-103 A/B. Next, the stream is heated to the reaction temperature of 320 °C by E-503 A/B. Process steam at 315 °C and 2200 kPa also enters the reactor at a flow rate of 7 kg/min to provide a hydrogen donor source. The steam and feed stream react in R-102 A/B to convert any carboxylic acids that were produced from the noncatlytic cracking in R-101 into alkanes. The steam also reacts with a majority of the alkene molecules and forms alkanes of the same carbon chain length. This results in a significant amount of CO2 produced, as well as smaller fuel intermediate molecules (C1-C6). R-102 A/B is 2.9 m in diameter and 17 m in length with a catalyst volume of 220 m^3. The products exit the reactor in Stream 65 at 320 °C and 2200 kPa at a flow rate of 230 kg/min and proceed to E-209 A/B, shown on Drawing 03-A-024/3.

Stream 49 from L-108 A/B on Drawing 02-A-024/5 flowing at a rate of 320 kg/min is first pressurized to 2400 kPa by L-109 A/B, shown on Drawing 03-A-024/2. Then it is heated to 320 °C in E-504 A/B prior to entering the diesel decarboxylation reactor (R-103 A/B). Process steam in stream 70 also enters R-103 A/B at a flow rate of 10 kg/min at 315 °C and 2200 kPa. As in R-102 A/B, R-103 A/B reacts the feed stream with the process steam to convert any carboxylic acids and alkene molecules that were produced during the noncatalytic cracking into alkanes. R-103 A/B is 3.2 m in diameter and 19 m in length, with a catalyst volume of 310 m^3. The products exit the reactor in Stream 71 at 320 °C and 2200 kPa at a flow rate of 330 kg/min. They then proceed to E-208 A/B shown on Drawing 03-A-024/4, for removal of light end products that were formed in the reactor.

Stream 65 from R-102 A/B shown on Drawing 03-A-024/1 is first cooled to 93 °C by E-209 A/B prior to entering Flash 7 (D-109). D-109 flashes the incoming feed to 103 kPa, and separates the light components formed during decarboxylation (C1-C4) from the naphtha range fuel intermediates (C4-C12). The gas products from D-109 exit in Stream 4 at 77 °C and 103 kPa and head to light end purification shown on Drawing 05-A-024/1 at a flow rate of 45 kg/min. The liquid products exit D-109 at 77 °C and 103 kPa in Stream 3. They then combine with Stream 74 from D-105 on Drawing 05-A-024/1 to form Stream 78 at 200 kg/min. Stream 78 then proceeds to D-205 shown on Drawing 04-A-024/2 for trim purification after being pressurized to 140 kPa by L-128 A/B.

Stream 71 from R-103 A/B on Drawing 03-A-024/2 is first cooled to 180 °C by E-208 A/B as shown on Drawing 03-A-024/4. It is then sent to flash 3 (D-103) to remove the majority of the light end products. D-103 flashes the incoming stream from 2170 kPa to 1720 kPa. The light ends exit D-103 in Stream 82 at 24 kg/min and 175 °C, and are sent to E-207 A/B on Drawing 05-A-024/1 for light end purification. The liquid products From D-103 enter D-104 and are further flashed to 103 kPa. Flash drum 4 removes any remaining light ends in the diesel fuel intermediates. The light ends exit D-104 in Stream 84 at 170 °C and a flow rate of 10 kg/min, and are pressurized to 240 kPa by G-103 A/B before being sent to light end purification shown on Drawing 05-A-024/1in stream 86. The liquid products exit D-104 at 170 °C at a flow rate of 290 kg/min, and are sent to trim purification on Drawing 04-A-024/3 in stream 85.

III.A.4. Trim Purification Section (Drawings 04-A-024/X)

Stream 78 enters the naphtha-jet cut column (D-205) shown on Drawing 04-A-024/2. D-205 separates the naphtha product (C5-C9) from the jet fuel product (C9-C12). D-205 has a height of 28 m, diameter of 1.7 m, 30 trays, and a feed tray of 7. The distillate exits D-205 at 115 °C and 120 kPa. It is then condensed at 38 °C by E-105 A/B, and pressurized to 140 kPa by L-119 A/B. The distillate, Stream 156, is sent to D-311 shown on Drawing 04-A-024/6 at a rate of 64 kg/min, and the reflux is sent back to the column in Stream 157 at a reflux ratio of 1.25. The bottoms exit D-205 at 190 °C and 130 kPa. They are heated to 200 °C by E-403 A/B, and pressurized to 190 kPa by L-120 A/B. The bottoms in Stream 163 are sent to E-1101 A/B shown on Drawing 04-A-024/6 at a rate of 140 kg/min.

Stream 85 from D-104 shown on Drawing 03-A-024/4 is pressurized to 210 kPa by L-110 A/B on Drawing 04-A-024/3. It is then heated to 200 °C by E-505 A/B. After heating, Stream 167 is sent to the jet diesel cut column (D-204) shown on Drawing 04-A-024/4.

Stream 167 enters D-204 on tray 13. D-204 splits the jet fuel product (C8-C15) from the diesel fuel no. 2 product (C16-C30). D-204 is 24 m tall, 2.6 m in diameter, and has 25 trays. The distillate exits D-204 at 240 °C and 115 kPa. It is then condensed at 41 °C by E-103 A/B, and pressurized to 130 kPa by L-112 A/B. The distillate products leave L-112 A/B in Stream 172 at a rate of 73 kg/min and is sent to E-1101A/B to be cooled further. The reflux is pumped back through the column in Stream 173 at a reflux ratio of 2.7. The bottoms exit the column at 290 °C and 140 kPa, and are heated to 300 °C by E-404 A/B. The bottoms are then pumped to 170 kPa in Stream 178 by L-113 A/B at a flow rate of 200 kg/min. Stream 178 then enters the diesel fuel oil cut column (D-206) shown on Drawing 04-A-024/5.

D-206 (Drawing 04-A-024/5) splits the diesel fuel range intermediates from the bottom fuel oil intermediates. This column is 37 m tall, 2.8 m in diameter, has 40 trays, and a feed to tray 28. The diesel fuel range molecules (C16-C21) exit the top of the column at 340 °C and 150 kPa. They are then cooled to 320 °C by E-107 A/B prior to being pressurized to 170 kPa by L-114 A/B. The reflux is then sent back to the column at a reflux ratio of 0.8, and the diesel fuel intermediates are sent to E-1102 A/B shown on Drawing 04-A-024/7 in Stream 184 at a flow rate of 210 kg/min. The fuel oil intermediates flow out the bottom of the column at 398 °C and 170 kPa. They are then heated in the reboiler (E-409 A/B) to 400 °C. The fuel oil intermediates are sent to E-1103 A/B shown on Drawing 04-A-024/7 in Stream 191 at a flow rate of 4 kg/min after being pressurized to 210 kPa by L-115 A/B.

Stream 156, from D-205 shown on Drawing 04-A-024/2, is combined with Stream 129 from E-407 A/B shown on Drawing 05-A-018/4 in D-311, shown on Drawing 04-A-024/6. They combine to form the naphtha stream product, Stream 193, at 71 °C and 120 kPa. Stream 193 is then pressurized to 170 kPa in Stream 199 at a flow rate of 210 kg/min and sent to storage.

Stream 163 from L-120 A/B on Drawing 04-A-024/2 and Stream 172 from L-112 A/B on Drawing 04-A-024/4 combine to form the jet fuel product stream, Stream 192, on Drawing 04-A-024/6. This stream is cooled to 32 °C by E-1101 A/B, pressurized to 170 kPa by L-118 A/B, Stream 200, and sent to storage at a rate of 210 kg/min.

Stream 184 is routed from L-114 A/B, as shown on Drawing 04-A-024/5, to E-1102 A/B and cooled to 55 °C. This stream, Stream 201, is then pressurized to 170 kPa by L-129 A/B, and sent to storage as the diesel fuel no. 2 product at a rate of 210 kg/min.

Stream 191 from L-115 A/B on Drawing 04-A-024/5 is cooled to 55 °C by E-1103 A/B on Drawing 04-A-024/7. The stream exiting the fuel oil cooler 1 (E-1103 A/B), Stream 204, is fuel oil no. 5, and is sent to the boiler to serve as fuel at a rate of 4 kg/min.

III.A.5. Light End Processing Section (Drawing 05-A-024/X)

Stream 82 from D-103 on Drawing 03-A-024/4 is cooled to 38 °C in E-207 A/B shown on Drawing 05-A-024/1 prior to entering flash 5 (D-105). Streams 86 from G-203 A/B and 56 from D-108, shown on Drawings 03-A-024/4 and 02-A-024/3, respectively, combine together and also enters D-105. D-105 separates the naphtha range fuel intermediates (C5-C7) from the light ends (C1-C4). The naphtha range intermediates exit D-105 out the bottom at 21 °C and 103 kPa in Stream 73. Stream 73 is then sent to D-312 shown on Drawing 03-A-024/3 at 23 kg/min. Stream 92 exits the top of D-105 at 21 °C and 103 kPa, and combines with Stream 4 from D-109 A/B on Drawing 03-A-024/3. The two streams combine to form Stream 93, which is at 36 °C and 103 kPa. Stream 93 flows to G-105, shown on Drawing 05-A-024/2, at 240 kg/min.

Stream 93 enters the light end compressor (G-105) shown on Drawing 05-A-024/2. G-105 is a three stage compressor. The stream is pressurized to 410 kPa and heated to 160 °C in the first stage. It is then cooled by the interstage cooler 1 (E-210 A/B) to 35 °C before entering the second stage of the compressor. The stream is then pressurized to 1520 kPa in stage two, and is also heated to 180 °C. It then flows through the interstage cooler 2 (E-211 A/B), and is cooled to 35 °C before entering the third stage. Stream 105 then exits G-105 at 145 °C and 3170 kPa, and proceeds to the syngas column (D-207), shown on Drawing 05-A-024/3, at 240 kg/min.

Stream 105 is cooled to 32 °C by E-204 A/B, as on shown Drawing 05-A-024/3. It then enters the syngas column (D-207) on tray 5. D-207 is 37 m tall and 2.7 m in diameter with 40 trays. The syngas column removes the syngas (C1-C3) from the butane and naphtha fuel range products. The syngas exits the top of the column at 0 °C and 2700 kPa, and is partially condensed at -20 °C by low temperature refrigerant in E-104 A/B. The syngas product is then sent to the boiler to be used as boiler feed in Stream 110 at 160 kg/min, and the reflux is sent back into the column at a reflux ratio of 0.5. The bottom product exits D-719 at 170 °C and 2790 kPa, and is heated to 180 °C by E-405 A/B. The bottom product is sent to the debutanizer column feed cooler (E-205 A/B) as Stream 115 at a rate of 82 kg/min.

Stream 115 is cooled to 120 °C by E-205 A/B (Drawing 05-A-024/4). This stream then enters D-210 (debutanizer column) on tray 8. D-210 is 11.5 m tall and 2.1 m in diameter, and contains 12 trays. D-210 removes the butane product from the heavier naphtha range products. The butane product exits the top of D-210 at 74 °C and 830 kPa. It is then partially condensed at 70 °C by E-106 A/B. The butane product is then sent to storage in Stream 123 at 21 kg/min. The reflux is sent back to the column at a reflux ratio of 5.3. The bottoms leave D-210 at 130 °C and 850 kPa, and are heated to 150 °C by E-407 A/B. The bottoms product, Stream 129 (64 kg/min), is then combined with Stream 156 on Drawing 04-A-024/6 to produce the Naphtha product which is routed to storage.

III.B. Economic Assessment

III.B.1. Broad Cost Estimate

The capital cost summary for the base design is shown in Table 38. This table shows the total capital investment needed to complete the project, and was developed as described in Chapter II. The FCI was found to be $100 million, and the TCI was estimated to be $130 million ± 40%.

III.B.2. Raw Material and Manufacturing Cost Estimate

The raw material cost is based on purchasing crude soybean oil for $0.60/kg [20]. The total raw material cost is $300 million per year.

The total manufacturing cost for the base design is $19 million per year, and $37 million per year on years the entire catalyst bed needs to be replaced. The manufacturing cost includes chemicals and catalysts costs, operating labor costs, maintenance costs, and utility costs. Table 39 shows the overall yearly operating expense summary for the base design. The plant has an operating factor of 95%. Intermediate results can be found in Appendix C, and communication records can be found in Appendix G.

The catalyst used for the decarboxylation reactors in the base design was a Ni catalyst. The initial charge for the catalyst (shown on the broad cost estimate) covers the total amount of catalyst needed (530,000 kg) for a price of $19 million. This amount is charged every four years in order to recharge the catalyst. It was assumed there was a 4% yearly depletion of the catalyst that needed to be replaced for the years in between. This results in a cost of $750,000 for those years. A quote from Johnson Matthey Catalysts was used for pricing ($28/m^3).

The base design consists of an equivalent of 24 major unit operations, which equates to 32 new operators to cover continuous operation, as described in Chapter II. An average operator salary of $62,800 was used, and taking into account an additional 15% for supervision, the yearly operating expense equates out to $2,300,000 per year [53]. The maintenance costs were found to be $6.1 million per year.

The utility costs is $9,600,000 per year. This value includes the boiler feed water, cooling water, electricity, refrigeration, process water, and natural gas needed to run the plant. The prices for all the utilities, except the electricity and natural gas, were priced based off of Turton heuristics. The natural gas and electricity values were found from typical ND and MN values [57].

III.B.3. Revenues

Revenue for the base design comes from the sales of jet fuel, diesel fuel no. 2, petroleum naphtha, butane, C5 product, nonaromatic raffinate, vacuum bottoms, and acetic acid. Shipping costs were not considered when calculating the amount of revenues generated.

The transportation fuels, jet fuel, diesel fuel no. 2, and petroleum naphtha, produce a revenue of $140 million/year. This value was based on the production 120,000 liquid m^3/year of petroleum naphtha that can be sold for $0.36/L, jet fuel at a rate of 170,000 liquid m^3/year which is sold for $0.37/L, and diesel fuel no. 2 produced at 170,000 liquid m^3/year and sold at $0.37/L. The remaining by products produce a revenue of $21.3 million/year. The total annual revenue for the base design is $160 million/year.

III.B.4. Overall Profitability

The cash flow sheet for the base design is shown in Table 40. The process has a NPV@12% of $(820 million) ±40%. The project produces a gross loss of income of $160 million per year, and has a DCFROR value of 0. The negative NPV@12% value and a DCFROR value less than 12% show that the investment is not profitable over the project lifecycle.

III.C. Break Even Point

With the current design and prices of products and raw materials, the process cannot cover the cost of the incoming soybean oil. In order for the process to break even at the current design, the price of soybean oil would have to be at an all-time low of $0.23/kg, or the product revenues would need to be higher. The cash flow sheet based on this raw material price is shown in Table 41.

In order to make the process more economically feasible, development of a process that produces more profitable by products was performed. This analysis is presented in Chapter IV. Also, processing of the heavy ends, vacuum bottoms, will help to both produce another more profitable by product and help produce a larger amount of transportation fuels. This analysis was performed in Chapter V. Additionally, an analysis with crop oil integration was performed in Chapter VI, and a hazard analysis was performed on the margin between the transportation fuel products and raw material cost in Chapter VII.

Table 14. Soybean oil composition.

Component	Weight %
Linolenic Acid	12%
Linoleic Acid	51%
Oleic Acid	23%
Stearic Acid	4%
Palmitic Acid	10%

Table 15. Raw materials list for base design.

Raw Material	Amount
Soybean Oil	600,000 m^3/year

Table 16. Transportation fuel products from base design.

Product	Amount (liquid m^3/year)
Petroleum Naphtha	120,000
Jet Fuel	170,000
Diesel Fuel No. 2	170,000

Table 17. Petroleum naphtha product properties from base design.

Specification	Measurement
Density at 15 °C	695 kg/m3
Total paraffins volume %	67%
Olefins volume %	1%
Aromatics volume %	16%
Initial boiling point	50 °C
Temperature at 5% recovered	52 °C
Temperature at 10% recovered	56 °C
Temperature at 20% recovered	63 °C
Temperature at 30% recovered	75 °C
Temperature at 40% recovered	77 °C
Temperature at 50% recovered	88 °C
Temperature at 60% recovered	95 °C
Temperature at 70% recovered	98 °C
Temperature at 80% recovered	113 °C
Temperature at 90% recovered	118 °C
Final boiling point	129 °C
Reid vapor pressure at 37.8 °C	117 kPa

Table 18. Jet fuel product properties from base design.

Specification	Measurement
Aromatics volume %	14 %
Temperature at 10% recovered	165 °C
Temperature at 50% recovered	202 °C
Temperature at 90% recovered	252 °C
Final boiling point	270 °C
Flash point	46 °C
Density at 15 °C	772 kg/m3
Freezing point	-46.1 °C
Viscosity at -20 °C,	3.0 mm2/s
Net heat of combustion	43.6 MJ/kg
Smoke point	26.83 mm
Cetane number	58.5

Table 19. Diesel fuel no. 2 product properties from base design.

Specification	Measurement
Flash point	118 °C
Water volume %	0%
Temperature at 90% recovered	334 °C
Kinematic viscosity at 40 °C	3.35 mm2/s
Cetane number	79.5
Aromaticity volume %	15 %
Cloud point	3.8 °C

Table 20. Byproduct production in base design.

Product	Amount (liquid m^3/year)
Acetic Acid	2,900
Butane	21,000
Vacuum Bottoms	210,000

Table 21. Butane product properties from base design.

Specification	Measurement
Vapor pressure at 37.8 °C	397 kPa
Temperature at 95% recovered	2.2 °C
Pentane and heavier volume %	2.0 %
Relative density at 15.6/15.6°C	0.58
Free water content	0

Table 22. Boiler fuel products produced in base design.

Fuel	Amount
Syngas	15,000,000 Nm^3 gas/year
Fuel Oil No. 5	39,000 liquid m^3/year

Table 23. Initial charge of requirements for base design.

Chemical/Catalyst	**Amount**
Ni/SiO_2 Catalyst	530,000 kg

Table 24. Utility requirements for base design.

Utility	**Amount**
Boiler Feed Water	5,200,000,000 kg/year
Cooling Water	54,000 m^3/year
Electricity	18,000,000 kW
Refrigeration (Low Temp)	280,000,000 kg/year
Process Steam	8,200,000 kg/year
Natural Gas	28,000,000 N m^3/year

Table 25. Equipment lettering system [47].

Letter	Definition
D	Process (Pressure) Vessels
E	Heat Exchangers
F	Storage Vessels
G	Gas Movers
L	Pumps
P	Package Units
Q	Furnaces
R	Reactors

Table 26. Equipment number codes and corresponding definitions for base design.

Code	Definition
D-100 Series	Flash Drums
D-200 Series	Distillation Columns
D-300 Series	Reflux Drums
E-100 Series	Column Condensers
E-200 Series	Cooler Heat Exchangers
E-400 Series	Column Reboilers
E-500 Series	Heater Heat Exchangers
E-1100 Series	Product Coolers
D-500 Series	Knockout Drums
G-100 Series	Compressors
L-100 Series	Pumps
P-100 Series	Refrigeration Unit
Q-100 Series	Boilers
R-100 Series	Reactors
1##	Unit Number
A	Equipment 1 for redundant equipment
B	Equipment 2 for redundant equipment

Table 27. Equipment naming system using example number D-101 A.

Code	D	100 Series	101	A
Definition	Pressure Vessels	Flash Drum	First Unit	Equipment piece 1 of 2

Table 28. Flash drum equipment list.

Equipment ID	Equipment Name/Description	Height (m)	Diameter (m)	Orientation	Pressure (kPa) Design Basis	Temperature (°C)	MOC
D-101	Flash 1	5.8	1.4	Vertical	690	210	Stainless Steel Clad
D-102	Flash 2	5.3	1.4	Vertical	140	150	Stainless Steel Clad
D-103	Flash 3	4.9	1.2	Vertical	1720	175	Carbon Steel
D-104	Flash 4	4.7	1.2	Vertical	103	170	Carbon Steel
D-105	Flash 5	5.4	1.4	Vertical	103	21	Carbon Steel
D-107	Acetic Flash 1	1.8	0.5	Horizontal	1380	215	Stainless Steel Clad
D-108	Acetic Flash 2	3.4	0.8	Horizontal	210	65	Stainless Steel Clad
D-109	Flash 7	2.7	0.7	Vertical	103	77	Carbon Steel

Table 29. Distillation column equipment list.

Equipment ID	Equipment Name/Description	Height (m)	Diameter (m)	Trays*	Feed Tray	Pressure (kPa)	Temperature (°C)	MOC: Body	MOC: Trays
D-201	Atmospheric Column	8.4	2.4	7	3	130	280	ss clad	ss
D-202	Vacuum Colum	20	2.9	20	5	28	330	ss clad	ss
D-204	Jet Diesel Cut	24	2.6	25	13	130	300	cs	ss
D-205	Naphtha-Jet Cut	28	1.7	30	7	130	200	cs	ss
D-206	Diesel-Fuel Oil Cut	37	2.8	40	28	140	530	cs	ss
D-207	Syngas Column	37	2.7	40	5	2750	180	cs	ss
D-210	Debutanizer	11.5	2.1	12	8	830	145	cs	ss

***** Based on sieve trays at 80% efficiency

Table 30. Reflux drum equipment list.

Equipment ID	Equipment Name/Description	Volume (m3)	Orientation	Length (m)	Diameter (m)	Temperature (°C)	Pressure (kPa)	Flow Rate (m3/min)	MOC
D-301	Atmospheric Column Reflux Drum	1.4	Horizontal	3	0.8	60	110	0.3	ss clad
D-302	Vacuum Column Reflux Drum	8.1	Horizontal	5.5	1.4	230	14	1.2	ss clad
D-304	Jet-Diesel Cut Reflux Drum	1.4	Horizontal	3	0.8	41	103	0.3	cs
D-305	Naphtha-Jet Cut Reflux Drum	1.4	Horizontal	3	0.8	38	110	0.2	cs
D-306	Diesel-Fuel Oil Cut Reflux Drum	3.8	Horizontal	4.3	1.1	320	110	0.7	cs
D-307	Syngas Column Reflux Drum	3.8	Horizontal	4.3	1.1	-20	2690	0.3	cs
D-308	Debutanizer Reflux Drum	2.4	Horizontal	3.7	0.9	70	810	0.2	cs
D-310	Acetic Acid Drum	0.1	Horizontal	1.2	0.3	93	210	0.01	ss clad
D-311	Naphtha Drum	2.4	Horizontal	3.7	0.9	71	120	0.4	cs
D-312	Flash 7 Drum	3.8	Horizontal	3.2	1.1	71	103	0.7	ss clad

Table 31. Heat exchanger equipment list.

Equipment ID	Equipment Name/Description	Area (m3)	Duty (kW)	Tube Inlet Temp (°C)	Tube Outlet Temp (°C)	Tube Pressure (kPa)	Tube MOC	Tube Fluid	Shell Inlet Temp (°C)	Shell Outlet Temp (°C)	Shell Pressure (kPa)	Shell MOC	Shell Fluid	Heat Transfer Coefficient (W/m2-°C)
E-101 A/B	Atmospheric Column Condenser	660	2500	210	60	124	ss	C7-C12 fuel intermediates	55	200	4550	cs	Boiler Feed Water	850
E-102 A/B	Vacuum Column Condenser	55	5500	315	230	21	ss	C12-C30 fuel intermediates	55	239	4550	cs	Medium Pressure Steam	850
E-103 A/B	Jet Diesel Cut Condenser	340	2900	240	41	115	ss	C8-C15 fuel intermediates	30	200	4550	cs	Boiler Feed Water	425
E-104 A/B	Syngas Condenser	75	580	0	-20	2700	cs	Syngas	-30	-23	380	cs	Refrigerant	510
E-105 A/B	Naphtha Jet Condenser	500	1600	115	38	120	cs	C7-C9 fuel intermediates	30	93	380	cs	Cooling Water	450
E-106 A/B	Debutanizer Condenser	44	760	74	70	830	cs	Butane Product	30	140	55	cs	Cooling Water	510
E-107 A/B	Diesel-Fuel Oil Cut Condenser	15	2200	340	320	150	cs	C12-C21 fuel intermediates	55	240	3340	cs	Medium Pressure Steam	850
E-201 A/B	Cracking Cross Exchanger	320	14000	430	230	1800	ss	C1-C50 Crackate	20	310	140	cs	Soybean Oil	280
E-202 A/B	Flash 2 Cooler	170	2700	210	150	690	ss	C7-C50 fuel intermediates	55	205	4550	cs	Boiler Feed Water	425
E-204 A/B	Light End Cooler	360	1400	145	32	3170	cs	C1-C6 fuel intermediates	30	120	4550	cs	Boiler Feed Water	425
E-205 A/B	Debutanizer Cooler	16	340	180	120	2760	cs	C4-C6 fuel intermediates	55	150	4550	cs	Boiler Feed Water	425
E-207 A/B	Pre-Flash 5 Cooler	41	400	180	38	1720	ss	Syngas	30	45	380	cs	Cooling Water	510
E-208 A/B	Post Diesel Decarbox Cooler	33	2800	320	180	2200	cs	C1-C30 fuel intermediates	55	240	4500	cs	Medium Pressure Steam	850
E-209 A/B	Post Naphtha Decarbox Cooler	74	3600	320	93	2200	cs	C1-C12 fuel intermediates	55	240	4550	cs	Medium Pressure Steam	850
E-210 A/B	Interstage Cooler 1	210	750	160	35	410	ss	C1-C6 fuel intermediates	30	150	4550	cs	Boiler Feed Water	450
E-211 A/B	Interstage Cooler 2	130	890	180	35	1520	ss	C1-C6 fuel intermediates	30	150	4550	cs	Boiler Feed Water	450
E-401 A/B	Atmospheric Column Reboiler	200	7300	400	330	4500	ss	High Pressure Steam	280	310	140	ss clad	C7-C50 fuel intermediates	540
E-402 A/B	Vacuum Column Reboiler	840	4300	400	330	4500	ss	High Pressure Steam	330	340	140	ss clad	Heavy Ends	340
E-403 A/B	Naphtha Jet Cut Reboiler	100	2400	240	240	3300	ss	Medium Pressure Steam	190	200	130	cs	C9-C12 fuel intermediates	540
E-404 A/B	Jet Diesel Cut Reboiler	170	3500	400	330	4500	ss	High Pressure Steam	290	300	140	cs	C16-C30 fuel intermediates	340

(continued)

Table 31. Cont.

Equipment ID	Equipment Name/Description	Area (m3)	Duty (kW)	Tube Inlet Temp (°C)	Tube Outlet Temp (°C)	Tube Pressure (kPa)	Tube MOC	Tube Fluid	Shell Inlet Temp (°C)	Shell Outlet Temp (°C)	Shell Pressure (kPa)	Shell MOC	Shell Fluid	Heat Transfer Coefficient (W/m2-°C)
E-405 A/B	Syngas Column Reboiler	19	1000	240	240	3300	ss	Medium Pressure Steam	170	180	2790	cs	C4-C6 fuel intermediates	850
E-407 A/B	Debutanizer Reboiler	11	900	240	240	3300	ss	Medium Pressure Steam	130	150	850	cs	C5-C6 fuel intermediates	850
E-409 A/B	Diesel Fuel Oil Cut Reboiler	200	2200	435	370	6000	ss	Superheated Steam	398	400	170	cs	C22-C30 fuel intermediates	450
E-502 A/B	TTCT Preheat	460	6300	435	370	6000	ss	Superheated Steam	310	410	1930	ss clad	Soybean Oil	340
E-503 A/B	Naphtha Decarbox Heater	43	3700	400	330	4500	ss	High Pressure Steam	60	320	2400	cs	C6-C12 fuel intermediates	540
E-504 A/B	Diesel Decarbox Heater	41	1800	400	330	4500	ss	High Pressure Steam	230	320	2400	cs	C12-C30 fuel intermediates	480
E-505 A/B	Pre Jet Diesel Cut Heat	22	540	240	240	3300	cs	Medium Pressure Steam	170	200	210	cs	C8-C30 fuel intermediates	480
E-1101 A/B	Jet Cooler	260	1200	150	32	130	cs	Jet Fuel Product	30	120	3170	cs	Boiler Feed Water	425
E-1102 A/B	Diesel Cooler	130	3000	320	55	170	cs	Diesel Fuel No. 2 Product	50	240	3340	cs	Medium Pressure Steam	850
E-1103 A/B	Fuel Oil Cooler 1	6	80	400	55	210	cs	Fuel Oil No. 5	50	240	3340	cs	Medium Pressure Steam	280

Table 32. Knockout drum equipment list.

Equipment ID	Equipment Name/Description	Volume (m3)	Orientation	Length (m)	Diameter (m)	Temperature (°C)	Pressure (kPa)	Flow Rate (m3/min)	MOC
D-505 A/B	Stage 1 Light End Knockout Drum	4	Horizontal	3.6	1.2	36	103	140	cs
D-506 A/B	Stage 2 Light End Knockout Drum	0.6	Horizontal	1.9	0.6	35	400	41	cs
D-507 A/B	Stage 3 Light End Knockout Drum	0.1	Horizontal	1	0.3	35	1500	11	cs

Table 33. Compressor equipment list.

Equipment ID	Equipment Name/Description	Stages	Inlet Pressure (kPa)	Outlet Pressure (kPa)	Inlet Temp (°C)	Outlet Temp (°C)	Flow Rate (m3/min)	Power (kW)	MOC	Fluid
G-101 A/B	Flash 2 Compressor	1	140	410	150	200	3.4	17	ss	C1-C8 fuel intermediates
G-103 A/B	Flash 5 Compressor	1	103	240	170	220	5.5	15	cs	C3-C7 fuel intermediates
G-105 Stage 1	Light End Compressor	3	103	410	36	160	140	630	cs	C1-C6 fuel intermediates
G-105 Stage 2	Light End Compressor	3	400	1520	35	180	40	630	cs	C1-C6 fuel intermediates
G-105 Stage 3	Light End Compressor	3	1500	3170	35	145	11	630	cs	C1-C6 fuel intermediates

Table 34. Pump equipment list.

Equipment ID	Equipment Name/Description	Power (kW)	Inlet Pressure (kPa)	Outlet Pressure (kPa)	Temperature (°C)	Fluid	MOC
L-101 A/B	PreCracking Pump	70	103	1930	310	Soybean Oil	ss
L-103 A/B	Pre Naphtha Decarbox	17	140	2400	60	C6-C12 fuel intermediates	ss
L-104 A/B	Atmospheric Reflux	1.6	90	140	60	C7-C12 fuel intermediates	ss
L-105 A/B	Atmospheric Bottoms	0.81	103	140	310	C13-C50 fuel intermediates	ss
L-106 A/B	Vacuum Column Bottom	4	35	140	330	Heavy Ends	ss
L-107 A/B	Vacuum Bottoms	0.76	103	140	340	Heavy Ends	ss
L-108 A/B	Vacuum Reflux	5	7	140	230	C12-C30 fuel intermediates	ss
L-109 A/B	PreDiesel Decarbox	29	140	2400	230	C12-C30 fuel intermediates	ss
L-110 A/B	PreJet-Diesel Cut Heat Pump	1	103	210	170	C8-C30 fuel intermediates	scs
L-111 A/B	Naphtha Product	0.2	120	170	71	Naphtha Product	cs
L-112 A/B	Jet Diesel Cut Reflux	4	83	130	41	C8-C15 fuel intermediates	cs
L-113 A/B	Jet Diesel Cut Bottoms	0.53	103	170	300	C16-C30 fuel intermediates	cs
L-114 A/B	Diesel Fuel Oil Cut Reflux	7	110	170	320	C16-C21 fuel intermediates	ss
L-115 A/B	Diesel Fuel Oil Cut Bottoms	0.03	140	210	400	C22-C30 fuel intermediates	ss
L-116 A/B	Flash 5 Pump	0.05	140	170	21	C6-C9 fuel intermediates	ss
L-118 A/B	Jet Fuel Product	0.54	103	170	32	Jet Fuel Product	cs

(continued)

Table 34. Cont.

Equipment ID	Equipment Name/Description	Power (kW)	Inlet Pressure (kPa)	Outlet Pressure (kPa)	Temperature (°C)	Fluid	MOC
L-119 A/B	Naphtha Jet Reflux	5	90	140	38	C7-C9 fuel intermediates	Cs
L-120 A/B	Naphtha Jet Bottoms	0.51	95	190	200	C9-C12 fuel intermediates	cs
L-121 A/ B	Debutanizer reflux	2	790	835	70	Butane	cs
L-127 A/B	Syngas Reflux	6	2675	2720	-20	Syngas	cs
L-128 A/B	Flash 7 Pump	0.25	103	140	71	C6-C9 fuel intermediates	cs
L-129 A/B	Diesel Product	0.33	140	170	55	Diesel Fuel No. 2 Product	cs
L-130 A/B	Vacuum Bottoms Product	1	42	140	340	Vacuum Bottoms	ss

Table 35. Reactor equipment list.

Equipment ID	Equipment Name/Description	Diameter (m)	Length (m)	Tubes	Catalyst (m3)	Residence Time (hr)	Temperature (°C)	Pressure (kPa)	MOC
R-101	TTCR	6.1	12.2	10300	N/A	1.17	430	1800	cs/inconel
R-102 A/B	Naphtha Decarboxylation Reactor	2.9	17	N/A	220	3.2	320	2200	ss clad
R-103 A/B	Diesel Decarboxylation Reactor	3.2	19	N/A	310	4.8	320	2200	ss clad

Table. 36 Drawing number codes and corresponding definitions for the base design.

Code	**Definition**
00	Entire Plant
01	Thermal Cracking Section
02	Purification Section
03	Decarboxylation Section
04	Trim Purification Section
05	Light End Processing
A	11x17" Drawing Size
022	Base Design Input/Output Diagram – Metric Units
023	Base Design Block Flow Diagram - Metric Units
024	Base Design Process Flow Diagram - Metric Units

Table 37. Drawing naming system using example number 00-A-001/1.

Code	00	A	001	/1
Definition	Plant Section	Drawing Size	Drawing Type	Sheet

Table 38. Broad cost estimate for the base design.

Equipment	Equipment Description	Number	Capacity/Size Specs	Purcahsed Equipment Cost: Year 2004	Purcahsed Equipment Cost: Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-101	Flash 1	1	Height: 5.8 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$11,750	$16,000	2.5	1	7	$110,000	$110,000
D-102	Flash 2	1	Height: 5.3 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$11,500	$15,000	2.5	1	7	$110,000	$110,000
D-103	Flash 3	1	Height: 4.9 m Inside Diameter: 1.2m Vertical Orientation MOC: Carbon Steel	$11,000	$15,000	1	2	6	$89,000	$89,000
D-104	Flash 4	1	Height: 4.7 m Inside Diameter: 1.2 m Vertical Orientation MOC: Carbon Steel	$11,000	$15,000	1	1	4	$59,000	$59,000
D-105	Flash 5	1	Height: 5.4 m Inside Diameter: 1.4 m Vertical Orientation MOC: Carbon Steel	$10,000	$13,000	1	1	4	$54,000	$54,000
D-107	Acetic Flash 1	1	Length: 1.8 m Inside Diameter: 0.5 m Horizontal Orientation MOC: Stainless Steel Clad	$1,500	$2,000	2.5	1.5	8	$16,000	$16,000
D-108	Acetic Flash 2	1	Length: 3.4 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$5,000	$6,700	2.5	1	7	$47,000	$47,000

(continued)

Table 38. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-109	Flash 7	1	Height: 2.7 m Inside Diameter: 0.7 m Vertical Orientation MOC: Carbon Steel	$3,000	$4,000	1	1	4	$16,000	$16,000
D-201	Atmospheric Column	1	Height: 8.4 m Diameter: 2.4 m Trays: 7 Feed: Tray 3 MOC: Stainless Steel Clad	$40,000	$54,000	2.5	1	7	$380,000	$380,000
D-201 Trays	Atmospheric Column Trays	7	Diameter: 2.4 m MOC: Stainless Steel	From Quote	$2,500	1	1	1.2	$3,000	$21,000
D-202	Vacuum Colum	1	Height: 20 m Diameter: 2.9 m Trays: 20 Feed: Tray 5 MOC: Stainless Steel Clad	70000	$94,000	2.5	1	7	$660,000	$660,000
D-202 Trays	Vacuum Column Trays	20	Diameter: 2.9 m MOC: Stainless Steel	From Quote	$2,800	1	1	1.2	$2,800	$56,000
D-204	Jet Diesel Cut	1	Height: 24 m Diameter: 2.6 m Trays: 25 Feed: Tray 13 MOC: Carbon Steel	50000	$67,000	1	1	4	$270,000	$270,000
D-204 Trays	Jet Diesel Cut Trays	25	Diameter: 2.6 m MOC: Stainless Steel	From Quote	$2,600	1	1.025	1.2	$3,200	$81,000
D-205	Naphtha-Jet Cut	1	Height: 27.5 m Diameter: 1.7 m Trays: 30 Feed: Tray 7 MOC: Carbon Steel	80000	$110,000	1	1	4	$430,000	$430,000

(continued)

Table 38. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-205 Trays	Naphtha-Jet Cut Trays	30	Diameter: 1.7 m MOC:Stainless Steel	From Quote	$2,100	1	1	1.2	$2,500	$76,000
D-206	Diesel-Fuel Oil Cut	1	Height: 37 m Diameter: 2.8 m Trays: 40 Feed: Tray 28 MOC: Carbon Steel	150000	$200,000	1	1	4	$810,000	$810,000
D-206 Trays	Diesel-Fuel Oil Cut Trays	40	Diameter: 2.8 m MOC: Stainless Steel	From Quote	$2,800	1	1	1.2	$3,300	$130,000
D-207	Syngas Column	1	Height: 37 m Diameter: 2.7 m Trays: 40 Feed: Tray 5 MOC: Carbon Steel	125000	$170,000	1	3	8	$1,300,000	$1,300,000
D-207 Trays	Syngas Trays	40	Diameter: 2.7 m MOC: Stainless Steel	From Quote	$2,700	1	1	1.2	$3,300	$130,000
D-210	Debutanizer	1	Height: 11.5 m Diameter: 2.1 m Trays: 12 Feed: Tray 8 MOC: Carbon Steel	45000	$60,000	1	2	6	$360,000	$360,000
D-210 Trays	Debutanizer Trays	12	Diameter: 2.1 m MOC:Stainless Steel	From Quote	$2,300	1	1.18	1.2	$3,300	$40,000
D-301	Atmospheric Column Reflux Drum	1	Length: 3 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	4000	$5,400	2.5	1	4	$21,000	$21,000
D-302	Vacuum Column Reflux Drum	1	Length: 5.5 m Inside Diameter: 1.4 m Horizontal Orientation MOC: Stainless Steel Clad	$7,000	$9,400	2.5	1	4	$38,000	$38,000

(continued)

Table 38. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-304	Jet-Diesel Cut Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	4000	$5,400	1	1	3	$16,000	$16,000
D-305	Naphtha-Jet Cut Reflux Drum	1	Length: 3 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	$4,000	$5,400	1	1	3	$16,000	$16,000
D-306	Diesel-Fuel Oil Cut Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	6000	$8,100	1	1	3	$24,000	$24,000
D-307	Syngas Column Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	$6,000	$8,100	1	1	3	$24,000	$24,000
D-308	Debutanizer Reflux Drum	1	Length: 3.7 m Inside Diameter: 0.9 m Horizontal Orientation MOC: Carbon Steel	5500	$7,400	1	1	3	$22,000	$22,000
D-310	Acetic Acid Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Stainless Steel Clad	$2,500	$3,400	2.5	1	4	$13,000	$13,000
D-311	Naphtha Drum	1	Length: 3.7 m Inside Diameter: 0.9 m Horizontal Orientation MOC: Carbon Steel	5500	$7,400	1	1	3	$22,000	$22,000
D-312	Flash 7 Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Stainless Steel Clad	$6,000	$8,100	2.5	1	4	$32,000	$32,000

(continued)

Table 38. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-505 A/B	Stage 1 Light End Knockout Drum	2	Height: 3.6 m Inside Diameter: 1.2 m Horizontal Orientation MOC: Carbon Steel	10000	$13,000	1	1	4	$54,000	$110,000
D-506 A/B	Stage 2 Light End Knockout Drum	2	Height: 1.9 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Carbon Steel	$4,000	$5,400	1	1	4	$21,000	$43,000
D-507 A/B	Stage 3 Light End Knockout Drum	2	Height: 1.0 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Carbon Steel	2000	$2,700	1	1	4	$11,000	$21,000
E-101 A/B	Atmosphereic Column Condenser	2	Surface Area: 660 m2 Heat Duty: 2500 kW MOC (shell/tube): cs/ss	$55,000	$74,000	1.7	1	4	$130,000	$250,000
E-102 A/B	Vacuum Column Condenser	2	Surface Area: 55 m2 Heat Duty: 5500 kW MOC (shell/tube): cs/ss	11000	$15,000	1.7	1	4	$59,000	$120,000
E-103 A/B	Jet Diesel Cut Condenser	2	Surface Area: 340 m2 Heat Duty: 2900 kW MOC (shell/tube): cs/ss	$32,000	$43,000	1.7	1	4	$170,000	$340,000
E-104 A/B	Syngas Condenser	2	Surface Area: 75 m2 Heat Duty: 580 kW MOC (shell/tube): cs/cs	12000	$16,000	1	1	3.2	$52,000	$100,000
E-105 A/B	Naphtha Jet Condenser	2	Surface Area: 500 m2 Heat Duty: 1600 kW MOC (shell/tube): cs/cs	$45,000	$60,000	1	1.1	3.2	$190,000	$390,000
E-106 A/B	Debutanizer Condenser	2	Surface Area: 44 m2 Heat Duty: 760 kW MOC (shell/tube): cs/cs	9500	$13,000	1	1	3.2	$41,000	$82,000

(continued)

Table 38. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-107 A/B	Diesel-Fuel Oil Cut Condenser	2	Surface Area: 15 m2 Heat Duty: 2200 kW MOC (shell/tube): cs/cs	$4,000	$5,400	1	1	3.2	$17,000	$34,000
E-201 A/B	Cracking Cross Exchanger	2	Surface Area: 320 m2 Heat Duty: 14,000 kW MOC (shell/tube): cs/ss	30000	$40,000	1.7	1	4	$160,000	$320,000
E-202 A/B	Flash 2 Cooler	2	Surface Area: 170 m2 Heat Duty: 2700 kW MOC (shell/tube): cs/ss	$15,000	$20,000	1.7	1.25	4	$81,000	$160,000
E-204 A/B	Light End Cooler	2	Surface Area: 360 m2 Heat Duty: 1400 kW MOC (shell/tube): cs/cs	35000	$47,000	1	1.1	3.25	$150,000	$310,000
E-205 A/B	Debutanizer Cooler	2	Surface Area: 16 m2 Heat Duty: 340 kW MOC (shell/tube): cs/cs	$4,000	$5,400	1	1	3.2	$17,000	$34,000
E-207 A/B	Pre-Flash 5 Cooler	2	Surface Area: 41 m2 Heat Duty: 400 kW MOC (shell/tube): cs/ss	9500	$13,000	1.7	1	4	$51,000	$100,000
E-208 A/B	Post Diesel Decarbox Cooler	2	Surface Area: 33 m2 Heat Duty: 2800 kW MOC (shell/tube): cs/cs	$8,000	$11,000	1	1	3.2	$34,000	$69,000
E-209 A/B	Post Naphtha Decarbox Cooler	2	Surface Area: 74 m2 Heat Duty: 3600 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3.2	$43,000	$86,000
E-210 A/B	Interstage Cooler 1	2	Surface Area: 210 m2 Heat Duty: 750 kW MOC (shell/tube): cs/ss	$22,500	$30,000	1.7	1	4	$120,000	$240,000

(continued)

Table 38. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-211 A/B	Interstage Cooler 2	2	Surface Area: 130 m2 Heat Duty: 890 kW MOC (shell/tube): cs/ss	$14,000	$19,000	1.7	1	4	$75,000	$150,000
E-401 A/B	Atmospheric Column Reboiler	2	Surface Area: 200 m2 Heat Duty: 7300 kW MOC (shell/tube): ss clad/ss	$22,500	$30,000	3	1.1	6	$180,000	$360,000
E-402 A/B	Vacuum Column Reboiler	2	Surface Area: 840 m2 Heat Duty: 4300 kW MOC (shell/tube): ss clad/ss	$60,000	$81,000	3	1.1	6	$480,000	$970,000
E-403 A/B	Naphtha Jet Cut Reboiler	2	Surface Area: 100 m2 Heat Duty: 2400 kW MOC (shell/tube): cs/ss	$12,000	$16,000	1.7	1	4	$64,000	$130,000
E-404 A/B	Jet Diesel Cut Reboiler	2	Surface Area: 170 m2 Heat Duty: 3500 kW MOC (shell/tube): cs/ss	$20,000	$27,000	1.7	1.1	4.5	$120,000	$240,000
E-405 A/B	Syngas Column Reboiler	2	Surface Area: 19 m2 Heat Duty: 1000 kW MOC (shell/tube): cs/ss	$8,000	$11,000	1.7	1.1	4.5	$48,000	$97,000
E-407 A/B	Debutanizer Reboiler	2	Surface Area: 11 m2 Heat Duty: 900 kW MOC (shell/tube): cs/ss	$4,000	$5,400	1.7	1.1	4.5	$24,000	$48,000
E-409 A/B	Diesel Fuel Oil Cut Reboiler	2	Surface Area: 200 m2 Heat Duty: 2200 kW MOC (shell/tube): cs/ss	$25,000	$34,000	1.7	1.1	4.5	$150,000	$300,000
E-502 A/B	TTCT Preheat	2	Surface Area: 460 m2 Heat Duty: 6300 kW MOC (shell/tube): ss clad /ss	$40,000	$54,000	3	1.25	7	$380,000	$750,000

(continued)

Table 38. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-503 A/B	Naphtha Decarbox Heater	2	Surface Area: 43 m2 Heat Duty: 3700 kW MOC (shell/tube): cs/ss	$10,000	$13,000	1.7	1.1	4.5	$60,000	$120,000
E-504 A/B	Diesel Decarbox Heater	2	Surface Area: 41 m2 Heat Duty: 1800 kW MOC (shell/tube): cs/ss	$10,000	$13,000	1.7	1.1	4.5	$60,000	$120,000
E-505 A/B	Pre Jet Diesel Cut Heat	2	Surface Area: 22 m2 Heat Duty: 540 kW MOC (shell/tube): cs/cs	$6,000	$8,100	1	1	3.2	$26,000	$52,000
E-1101 A/B	Jet Cooler	2	Surface Area: 260 m2 Heat Duty: 1200 kW MOC (shell/tube): cs/cs	$27,500	$37,000	1	1	3.2	$120,000	$240,000
E-1102 A/B	Diesel Cooler	2	Surface Area: 130 m2 Heat Duty: 3000 kW MOC (shell/tube): cs/cs	$14,000	$19,000	1	1	3.2	$60,000	$120,000
E-1103 A/B	Fuel Oil Cooler 1	2	Surface Area: 6 m2 Heat Duty: 80 kW MOC (shell/tube): cs/cs	$3,000	$4,000	1	1	3.2	$13,000	$26,000
G-101 A/B	Flash 2 Compressor	2	Power: 17 kW Number of Stages: 1 MOC: Stainless Steel	From Quote	$18,000	1	1	2.52	$46,000	$91,000
G-103 A/B	Flash 5 Compressor	2	Power: 15 kW Number of Stages: 1 MOC: Carbon Steel	From Quote	$16,000	1	1	2.5	$41,000	$81,000
G-105	Light End Compressor	1	Power: 1900 kW Number of Stages: 3 MOC: Carbon Steel	From Quote	$2,000,000	1	1	2.5	$5,000,000	$5,000,000

(continued)

Table 38. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-101 A/B	PreCracking Pump	2	Power: 70 kW Suction Pressure: 110 kPa MOC: Stainless Steel	$12,500	$17,000	1.9	1	4.5	$76,000	$150,000
L-103 A/B	Pre Naphtha Decarbox	2	Power: 17 kW Suction Pressure: 120 kPa MOC: Stainless Steel	$10,000	$13,000	1.9	1	4.5	$60,000	$120,000
L-104 A/B	Atmospheric Reflux	2	Power: 1.6 kW Suction Pressure: 100 kPa MOC: Stainless Steel	$4,000	$5,400	1.9	1	3.2	$17,000	$34,000
L-105 A/B	Atmospheric Bottoms	2	Power: 810 W Suction Pressure: 110 kPa MOC: Stainless Steel	$3,900	$5,200	1.9	1	3.2	$17,000	$34,000
L-106 A/B	Vacuum Column Bottom	2	Power: 4.3 kW Suction Pressure: 33 kPa MOC: Stainless Steel	$5,000	$6,700	1.9	1	3.2	$21,000	$43,000
L-107 A/B	Vacuum Bottoms	2	Power: 760 W Suction Pressure: 100 kPa MOC: Stainless Steel	$3,800	$5,100	1.9	1	3.2	$16,000	$33,000
L-108 A/B	Vacumm Reflux	2	Power: 5.1 kW Suction Pressure: 100 kPa MOC: Stainless Steel	$5,500	$7,400	1.9	1	3.2	$24,000	$47,000
L-109 A/B	PreDiesel Decarbox	2	Power: 29 kW Suction Pressure: 120 kPa MOC: Stainless Steel	$10,750	$14,000	1.9	1	4.5	$65,000	$130,000
L-110 A/B	PreJet-Diesel Cut Heat Pump	2	Power: 1.1 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$4,000	$5,400	1.4	1	3.2	$17,000	$34,000

(continued)

Table 38. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-111 A/B	Naphtha Product	2	Power: 200 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,200	$4,300	1.4	1	3.2	$14,000	$28,000
L-112 A/B	Jet Diesel Cut Reflux	2	Power: 4.4 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$5,250	$7,100	1.4	1	3.2	$23,000	$45,000
L-113 A/B	Jet Diesel Cut Bottoms	2	Power: 530 W Suction Pressure: 120 kPa MOC: Carbon Steel	$3,500	$4,700	1.4	1	3.2	$15,000	$30,000
L-114 A/B	Diesel Fuel Oil Cut Reflux	2	Power: 6.7 kW Suction Pressure: 100 kPa MOC: Stainless Steel	$8,500	$11,000	1.9	1	3.2	$37,000	$73,000
L-115 A/B	Diesel Fuel Oil Cut Bottoms	2	Power: 31 W Suction Pressure: 140 kPa MOC: Stainless Steel	$2,500	$3,400	1.9	1	3.2	$11,000	$21,000
L-116 A/B	Flash 5 Pump	2	Power: 48 W Suction Pressure: 100 kPa MOC: Stainless Steel	$2,750	$3,700	1.9	1	3.2	$12,000	$24,000
L-118 A/B	Jet Fuel Product	2	Power: 540 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,500	$4,700	1.4	1	3.2	$15,000	$30,000
L-119 A/B	Naphtha Jet Reflux	2	Power: 5.0 kW Suction Pressure: 110 kPa MOC: Carbon Steel	$5,250	$7,100	1.4	1	3.2	$23,000	$45,000
L-120 A/B	Naphtha Jet Bottoms	2	Power: 510 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,250	$4,400	1.4	1	3.2	$14,000	$28,000

(continued)

Table 38. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-121 A/ B	Debutanizer reflux	2	Power: 1.7 kW Suction Pressure: 820 kPa MOC: Carbon Steel	$4,200	$5,600	1.4	1	3.2	$18,000	$36,000
L-127 A/B	Syngas Reflux	2	Power: 6 kW Suction Pressure: 2700 kPa MOC: Carbon Steel	$5,500	$7,400	1.4	1	3.2	$24,000	$47,000
L-128 A/B	Flash 7 Pump	2	Power: 250 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,300	$4,400	1.4	1	3.2	$14,000	$28,000
L-129 A/B	Diesel Product	2	Power: 330 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,400	$4,600	1.4	1	3.2	$15,000	$29,000
L-130 A/B	Vacuum Bottoms Product	2	Power: 400 W Suction Pressure: 42 kPa MOC: Stainless Steel	$3,400	$4,600	1.9	1	3.2	$15,000	$29,000
P-101	Refrigeration System	1	Load: 820-890 metric tons Power: 200 Volts	From Quote	$1,800,000	1	1	3.2	$5,900,000	$5,900,000
Q-101	TTCR Boiler	1	Duty: 65,000 kW	From Quote	$2,100,000	1	1	3.2	$6,700,000	$6,700,000
Q-102	High Pressure Steam Boiler	1	Duty: 78,000 kW	From Quote	$2,300,000	1	1	3.2	$7,400,000	$7,400,000
R-101	TTCR	1	Diameter: 6.1 m Length: 12.2 m Tubes: 10300 MOC: cs/inconel	From Quote	$30,000,000	0.7	1	3.2	$21,000,000	$21,000,000

(continued)

Table 38. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
R-102 A/B	Naphtha Decarboxylation Reactor	2	Diameter: 2.9 m Length: 17 m MOC: Stainless Steel Clad	From Quote	$840,000	1	1	3.2	$2,700,000	$5,400,000
R-103 A/B	Diesel Decarboxylation Reactor	2	Diameter: 3.2 m Length: 19 m MOC: Stainless Steel Clad	From Quote	$1,000,000	1	1	3.2	$3,300,000	$6,700,000

Total Bare Module Cost	CTBM	$71,000,000
Contingency and Fees	CTBM*0.18	$13,000,000
Total Module Cost	CTM	$84,000,000
Auxiliary Facicilites	CTM*0.2	$17,000,000
Fixed Capital Investment	FCI	$100,000,000
Working Capital	FCI*0.15	$15,000,000
Chemicals & Catalysts		$19,000,000
Total Capital Investment	TCI	$130,000,000

Notes: Actual numbers may be off due to rounding

Table 39. Operating expense summary for base design.

Year	Chemicals & Catalysts	Operating Labor	Maintenance	Utilities	Yearly Total
1	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000
2	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000
3	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000
4	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000
5	$ 19,000,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 37,000,000
6	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000
7	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000
8	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000
9	$ 14,000,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 37,000,000
10	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000
11	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000
12	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000
13	$ 19,000,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 37,000,000
14	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000
15	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000
16	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000
17	$ 19,000,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 37,000,000
18	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000
19	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000
20	$ 750,000	$ 2,300,000	$ 6,100,000	$ 9,600,000	$ 19,000,000

Notes: Actual numbers may be off due to rounding

Table 40. Cash flow sheet for base design.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR	Present Value @ DCFROR
-1	$-	$-	$-	$-	$-	$-	$-	($51,000)	($51,000)	($57,000)	($51,000)
0	$-	$-	$-	$-	$-	$-	$-	($84,000)	($84,000)	($84,000)	($84,000)
1	$160,000	$300,000	$19,000	($160,000)	($16,000)	($170,000)	($72,000)		($87,000)	($77,000)	($87,000)
2	$160,000	$300,000	$19,000	($160,000)	($14,000)	($170,000)	($71,000)		($87,000)	($70,000)	($87,000)
3	$160,000	$300,000	$19,000	($160,000)	($12,000)	($170,000)	($71,000)		($88,000)	($63,000)	($88,000)
4	$160,000	$300,000	$19,000	($160,000)	($11,000)	($170,000)	($70,000)		($89,000)	($56,000)	($89,000)
5	$160,000	$300,000	$37,000	($180,000)	($9,600)	($190,000)	($77,000)		($100,000)	($57,000)	($100,000)
6	$160,000	$300,000	$19,000	($160,000)	($8,500)	($170,000)	($69,000)		($90,000)	($45,000)	($90,000)
7	$160,000	$300,000	$19,000	($160,000)	($7,500)	($170,000)	($69,000)		($90,000)	($41,000)	($90,000)
8	$160,000	$300,000	$19,000	($160,000)	($6,600)	($170,000)	($68,000)		($90,000)	($36,000)	($90,000)
9	$160,000	$300,000	$37,000	($180,000)	($5,800)	($180,000)	($76,000)		($100,000)	($36,000)	($100,000)
10	$160,000	$300,000	$19,000	($160,000)	($5,500)	($160,000)	($68,000)		($91,000)	($29,000)	($91,000)
11	$160,000	$300,000	$19,000	($160,000)	($5,500)	($160,000)	($68,000)		($91,000)	($26,000)	($91,000)
12	$160,000	$300,000	$19,000	($160,000)	($5,500)	($160,000)	($68,000)		($91,000)	($23,000)	($91,000)
13	$160,000	$300,000	$37,000	($180,000)	($5,500)	($180,000)	($75,000)		($100,000)	($23,000)	($100,000)
14	$160,000	$300,000	$19,000	($160,000)	($5,500)	($160,000)	($68,000)		($91,000)	($19,000)	($91,000)
15	$160,000	$300,000	$19,000	($160,000)	($5,500)	($160,000)	($68,000)		($91,000)	($17,000)	($91,000)
16	$160,000	$300,000	$19,000	($160,000)	($5,500)	($160,000)	($68,000)		($91,000)	($15,000)	($91,000)
17	$160,000	$300,000	$37,000	($180,000)	($5,500)	($180,000)	($75,000)		($100,000)	($15,000)	($100,000)
18	$160,000	$300,000	$19,000	($160,000)		($160,000)	($66,000)		($93,000)	($12,000)	($93,000)
19	$160,000	$300,000	$19,000	($160,000)		($160,000)	($66,000)		($93,000)	($11,000)	($93,000)
20	$160,000	$300,000	$19,000	($160,000)		($160,000)	($66,000)	$15,000	($78,000)	($8,100)	($78,000)
									NPV@HR	$ (820,000)	$ (2,000,000)
									DCFROR	0%	
									HR	12%	

Notes: Dollar values are in thousands

Actual numbers may be off due to rounding

Numbers in parenthesis represent negative numbers

Table 41. Cash flow sheet for base design and a soybean oil cost of $0.23/kg.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR
-1	$-	$-	$-	$-	$-	$-	$-	($51,000)	($51,000)	($57,000)
0	$-	$-	$-	$-	$-	$-	$-	($84,000)	($84,000)	($84,000)
1	$160,000	$110,000	$19,000	$28,000	($16,000)	$13,000	($5,200)		$23,000	$21,000
2	$160,000	$110,000	$19,000	$28,000	($14,000)	$14,000	($6,000)		$22,000	$18,000
3	$160,000	$110,000	$19,000	$28,000	($12,000)	$16,000	($6,700)		$22,000	$16,000
4	$160,000	$110,000	$19,000	$28,000	($11,000)	$18,000	($7,300)		$21,000	$13,000
5	$160,000	$110,000	$37,000	$11,000	($9,600)	$920	($380)		$10,000	$5,800
6	$160,000	$110,000	$19,000	$28,000	($8,500)	$20,000	($8,300)		$20,000	$10,000
7	$160,000	$110,000	$19,000	$28,000	($7,500)	$21,000	($8,700)		$20,000	$8,900
8	$160,000	$110,000	$19,000	$28,000	($6,600)	$22,000	($9,000)		$19,000	$7,800
9	$160,000	$110,000	$37,000	$11,000	($5,800)	$4,700	($1,900)		$8,600	$3,100
10	$160,000	$110,000	$19,000	$28,000	($5,500)	$23,000	($9,500)		$19,000	$6,100
11	$160,000	$110,000	$19,000	$28,000	($5,500)	$23,000	($9,500)		$19,000	$5,400
12	$160,000	$110,000	$19,000	$28,000	($5,500)	$23,000	($9,500)		$19,000	$4,900
13	$160,000	$110,000	$37,000	$11,000	($5,500)	$5,100	($2,100)		$8,400	$1,900
14	$160,000	$110,000	$19,000	$28,000	($5,500)	$23,000	($9,500)		$19,000	$3,900
15	$160,000	$110,000	$19,000	$28,000	($5,500)	$23,000	($9,500)		$19,000	$3,500
16	$160,000	$110,000	$19,000	$28,000	($5,500)	$23,000	($9,500)		$19,000	$3,100
17	$160,000	$110,000	$37,000	$11,000	($5,500)	$5,100	($2,100)		$8,400	$1,200
18	$160,000	$110,000	$19,000	$28,000		$28,000	($12,000)		$17,000	$2,200
19	$160,000	$110,000	$19,000	$28,000		$28,000	($12,000)		$17,000	$1,900
20	$160,000	$110,000	$19,000	$28,000		$28,000	($12,000)	$15,000	$32,000	$3,300

NPV@HR	$ 0
DCFROR	12%
HR	12%

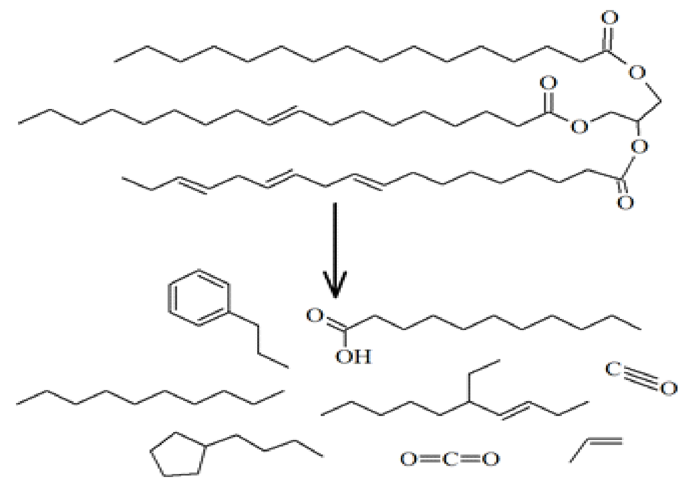
Notes: Dollar values are in thousands

Actual numbers may be off due to rounding

Numbers in parenthesis represent negative numbers

Soybean Oil: 600 liquid km^3/year

Process Steam: 19 N Mm^3 gas/year



Syn Gas: 15,000 N km^3 gas/year

Acetic Acid: 2.9 liquid km^3/year

Butane: 21 liquid km^3/year

Petroleum Naphtha: 120 liquid km^3/year

Jet Fuel: 170 liquid km^3/year

Diesel Fuel No. 2: 170 liquid km^3/year

Fuel Oi No. 5l: 39 liquid km^3/year

Vacuum Bottoms: 210 liquid km^3/year

Notes

1. Material balance may be off due to rounding errors.

Special Symbols / Nomenclature

Reference Drawings:

Block Flow Diagram
00-A-023

Process Flow Diagram
00-A-024

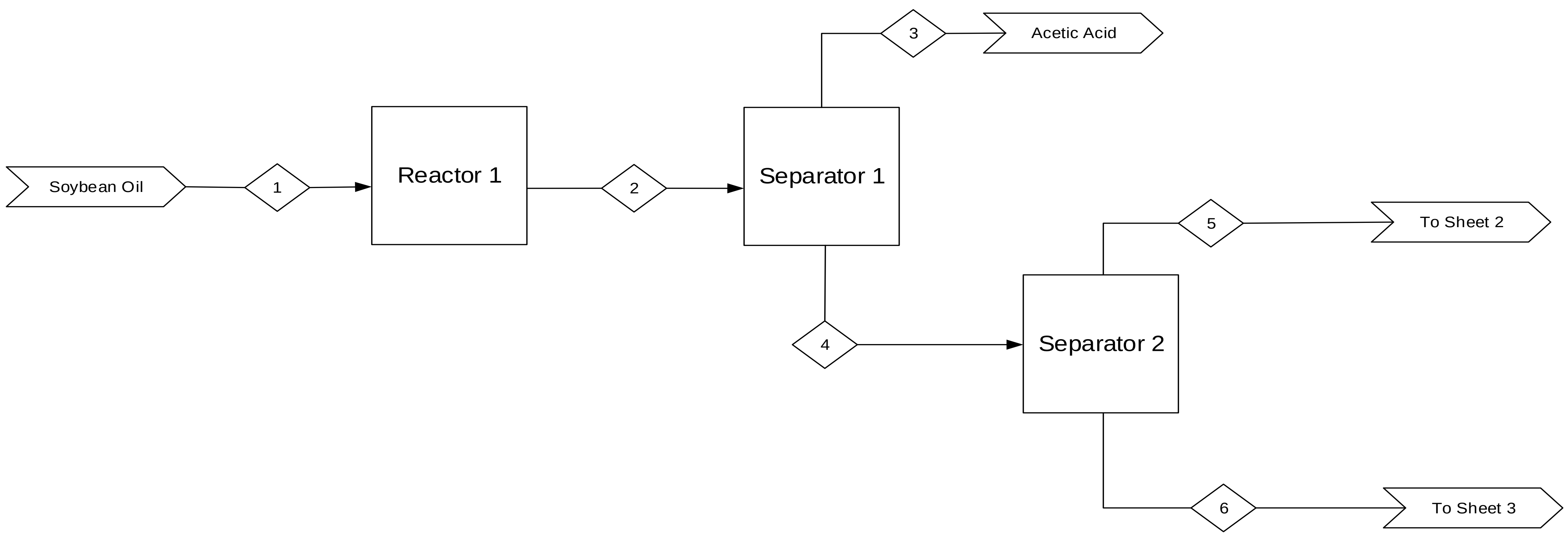
Drawing Type

Input/Output Diagram

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-25-17	00-A-022	0



Component/Stream (kg/min)	1	2	3	4	5	6
Soybean Oil	1000	0	0	0	0	0
Acetic Acid	0	0	5	0	0	0
C1-C50	0	1000	0	1000	0	0
C1-C12	0	0	0	0	440	0
C12-C50	0	0	0	0	0	550
Total	1000	1000	5	1000	440	550

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 1: Crack incoming TG oil into fuel intermediates

Separator 1:Separate aqueous acetic acid from organic crackate

Separator 2: Separate the naphtha range fuel intermediates from the diesel range fuel intermediates

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

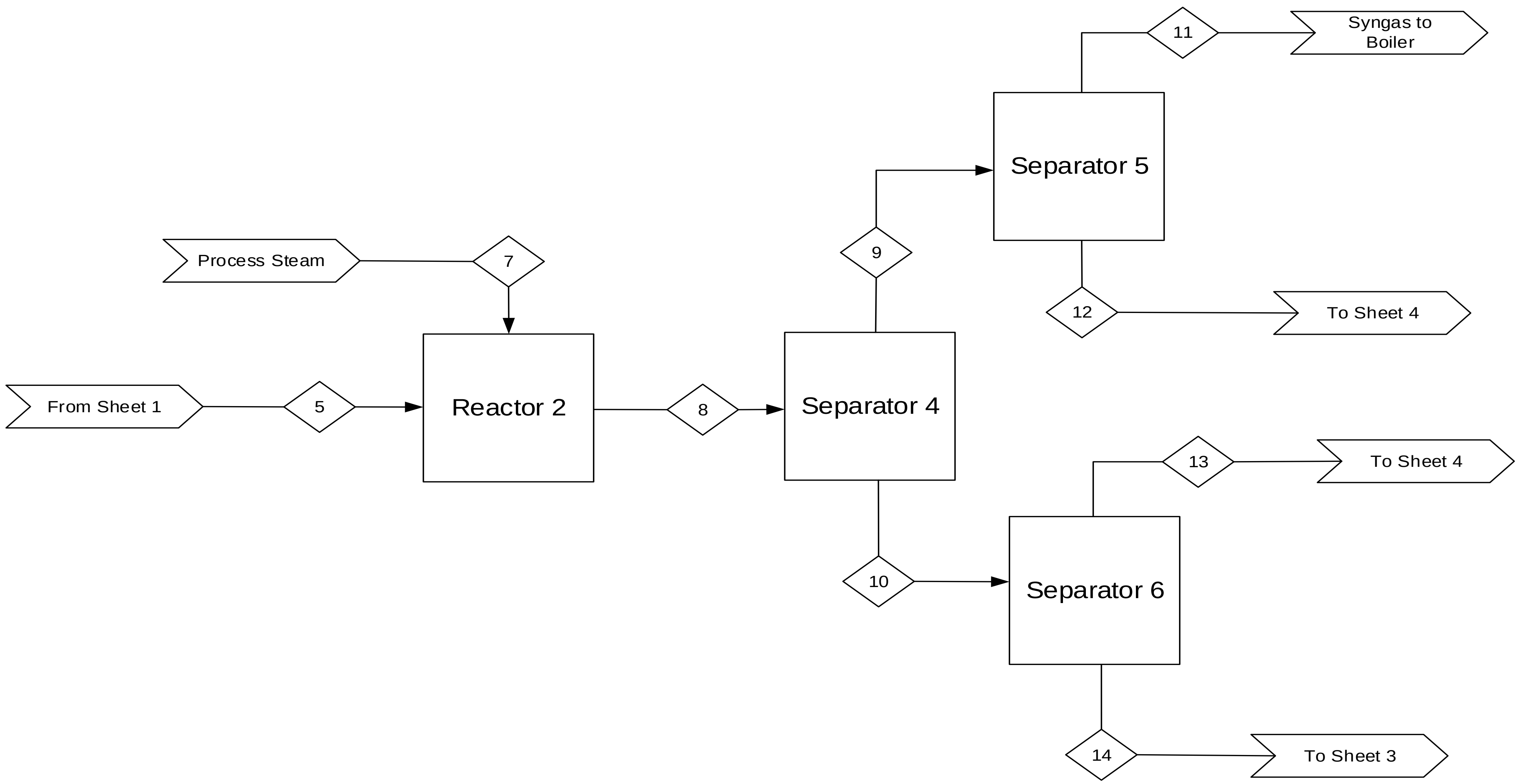
Input/Output Diagram
00-A-022

Process Flow Diagram
00-A-024

Drawing Type
Block Flow Diagrams

Title
Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-25-17	00-A-023/1	0



Component/Stream (kg/min)	5	7	8	9	10	11	12	13	14
C1-C12	440	0	440	0	0	0	0	0	0
Steam	0	7	0	0	0	0	0	0	0
C1-C6	0	0	0	240	0	0	0	0	0
C1-C3	0	0	0	0	0	160	0	0	0
C4-C6	0	0	0	0	0	0	82	0	0
C7-C10	0	0	0	0	0	0	0	64	0
C11-C13	0	0	0	0	0	0	0	0	140
C7-C13	0	0	0	0	200	0	0	0	0
Total	440	7	440	240	200	160	82	64	140

Notes

1. Drawing not to scale.
2. Mass balance may be off due to rounding.
3. Stream numbers do not correspond with PFD stream numbers.
4. Mass balances shown in kg/min.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Assume 100% separation in separators.
7. Reactor 2: Reacts the carboxylic acids and alkenes to produce hydrocarbons.

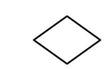
Separator 4: Removes light ends from naphtha range fuel intermediates.

Separator 5: Removes syngas from butane and naphtha intermediates.

Separator 6: Separates petroleum naphtha intermediates from jet fuel range fuel intermediates.

Special Symbols / Nomenclature


Input/Output


Stream Indicator

Reference Drawings:

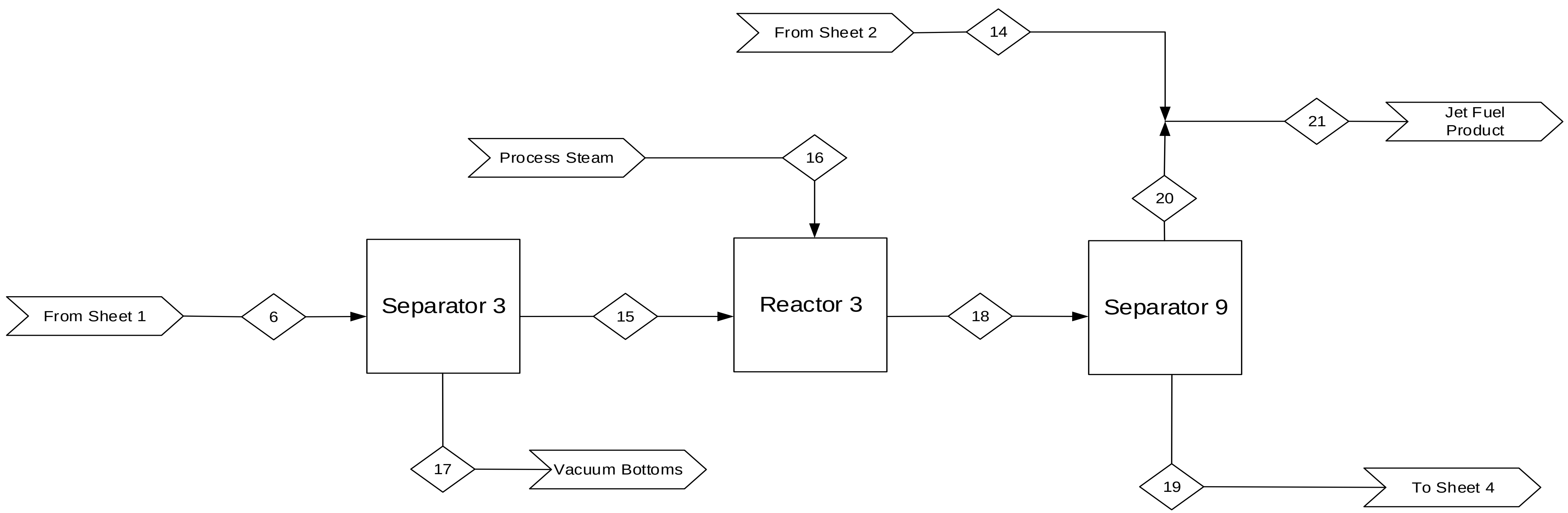
Input/Output Diagram
00-A-022

Process Flow Diagram
00-A-024

Drawing Type
Block Flow Diagram

Title
Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-25-17	00-A-023/2	0



Component/Stream (kg/min)	6	14	15	16	17	18	19	20	21
Steam	0	0	0	9	0	0	0	0	0
C12-C50	550	0	0	0	0	0	0	0	0
C30-C50	0	0	0	0	280	0	0	0	0
C12-C30	0	0	280	0	0	290	0	0	0
C13-C15	0	0	0	0	0	0	0	73	0
C11-C13	0	140	0	0	0	0	0	0	0
C11-C15	0	0	0	0	0	0	0	0	210
C15-C30	0	0	0	0	0	0	220	0	0
Total	550	140	280	9	280	290	220	73	210

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 3: Reacts carboxylic acids and alkenes to produce hydrocarbons.

Separator 3: Separates diesel fuel range intermediates from the vacuum bottoms.

Separator 9: Separates jet fuel range fuel intermediates from diesel fuel range intermediates.

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-022

Process Flow Diagram
00-A-024

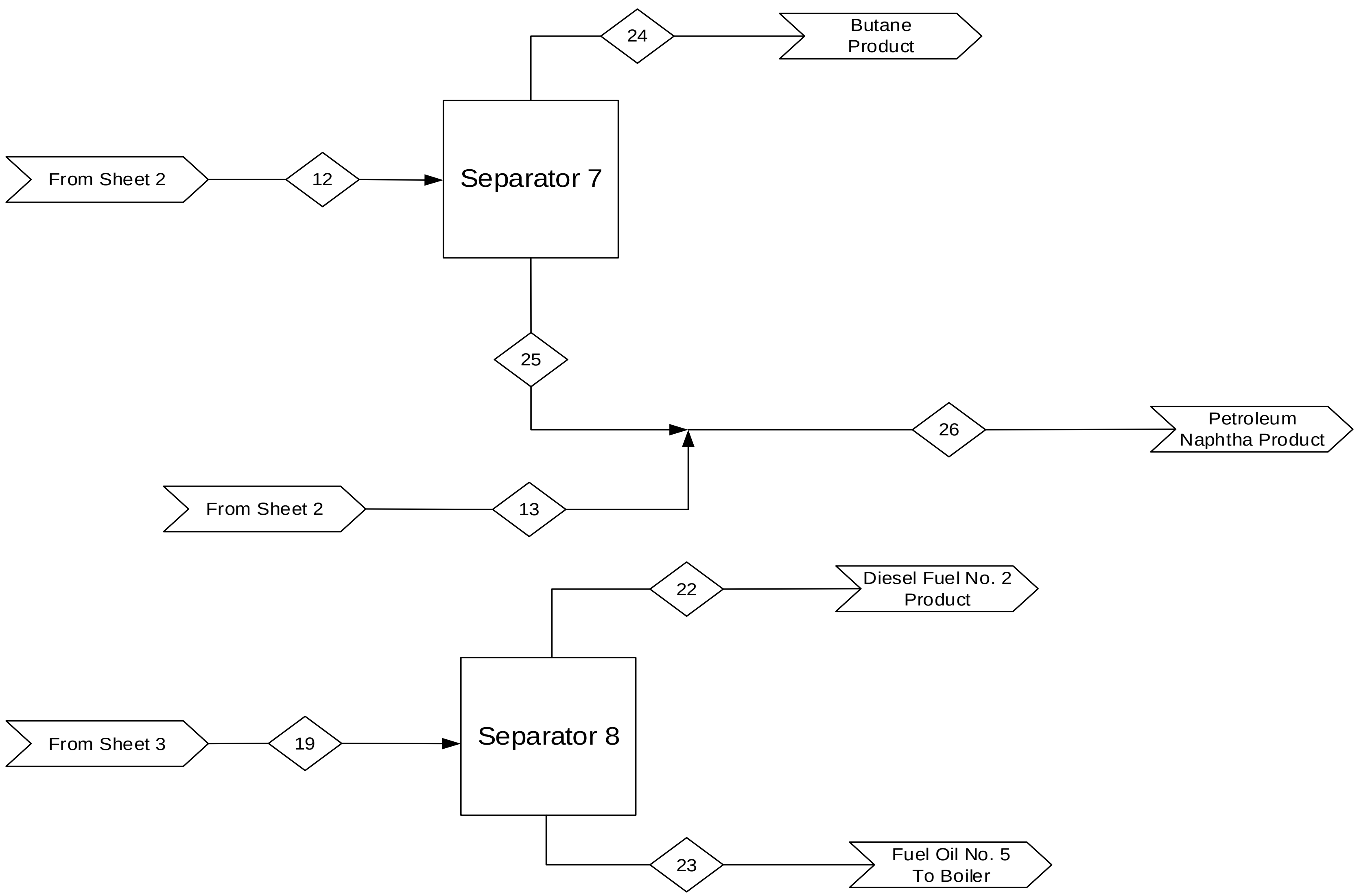
Drawing Type

Block Flow Diagram

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-25-17	00-A-023/3	0



Component/Stream (kg/min)	12	13	19	22	23	24	25	26
C4-C6	82	0	0	0	0	0	0	0
C4	0	0	0	0	0	20	0	0
C5-C6	0	0	0	0	0	0	64	0
C7-C10	0	64	0	0	0	0	0	0
C5-C10	0	0	0	0	0	0	0	130
C15-C22	0	0	0	210	0	0	0	0
C23-C30	0	0	0	0	4	0	0	0
C15-C30	0	0	220	0	0	0	0	0
Total	82	64	220	210	4	20	64	130

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

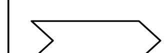
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

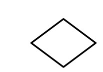
6. Assume 100% separation in separators.

7. Separator 7: Separates butane byproduct from naphtha range intermediates.

Separator 8: Separates the diesel fuel no. 2 product from the fuel oi no 5. product.

Special Symbols / Nomenclature


Input/Output


Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-022

Process Flow Diagram
00-A-024

Drawing Type

Block Flow Diagram

Title

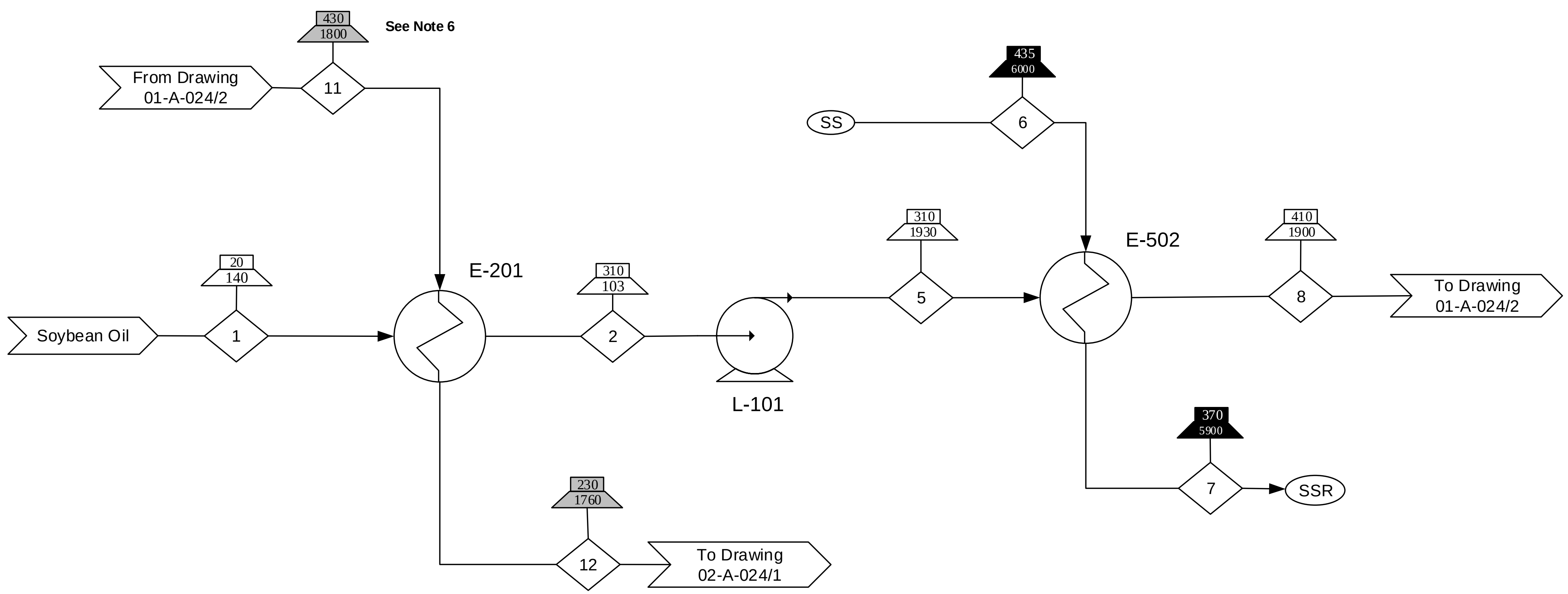
Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-25-17	00-A-023/4	0

E-201 A/B
Post Cracking Cooler
Area = 320 m^2
Duty = 14,000 kW

E-502 A/B
TTCR Preheat
Area = 460 m^2
Duty = 6300 kW

L-101 A/B
PreCracking Pump
Power = 70 kW



Component/Stream (kg/min)	1	2	5	6	7	8	11	12
Soybean Oil	1000	1000	1000	0	0	1000	0	0
C1-C50	0	0	0	0	0	0	1000	1000
Water	0	0	0	2400	2400	0	0	0
Total	1000	1000	1000	2400	2400	1000	1000	1000

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 11 and 12 is an organic, aqueous, gaseous three phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase
SS Superheated Steam
SSR Superheated Steam Recycle

Reference Drawings:

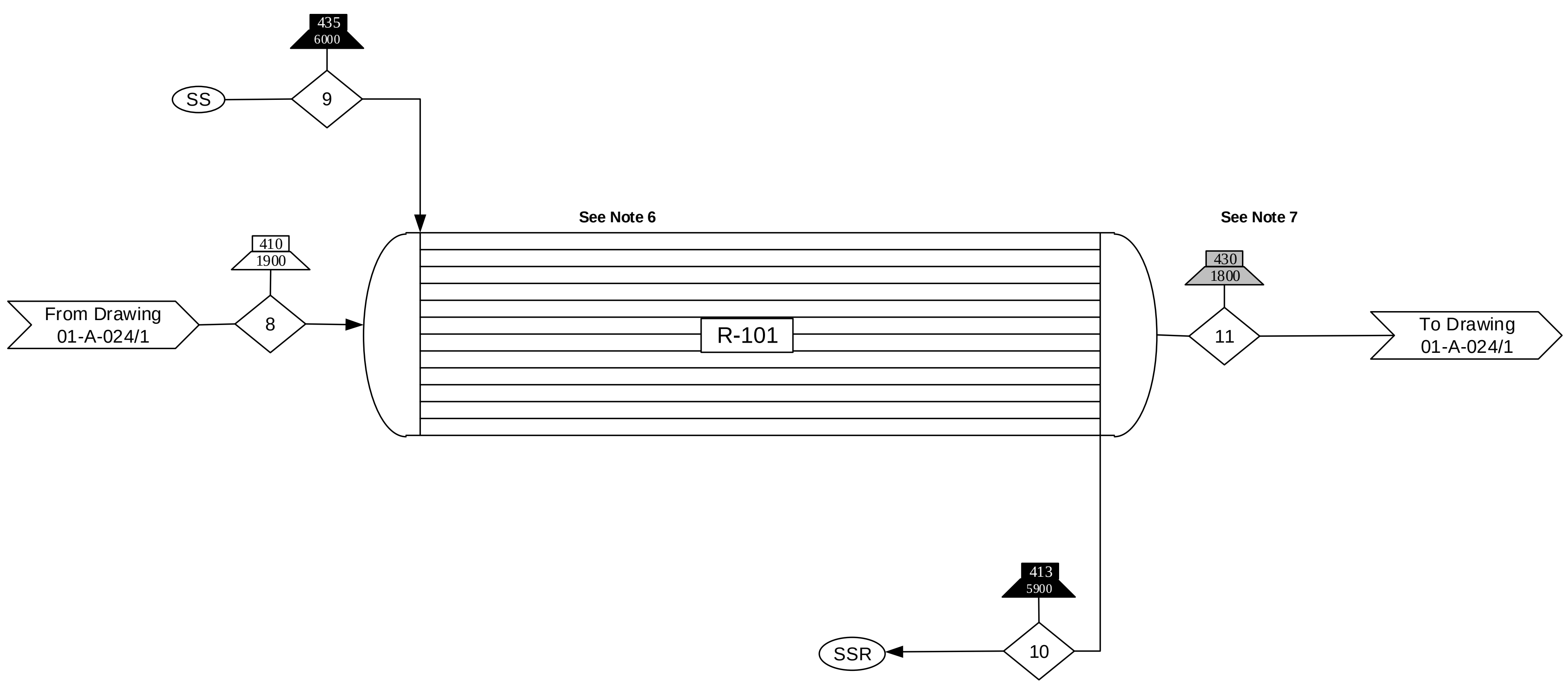
Input/Output Diagram
00-A-022
Block Flow Diagrams
00-A-023
Process Flow Diagrams
01-A-024

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design - Thermal Cracking Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-25-17	01-A-024/1	0

R-101
TTCR
Diameter= 6.1 m
Length= 12.2 m
Tubes= 10300



Component/Stream (kg/min)	8	9	10	11
Soybean Oil	1000	0	0	0
C1-C50	0	0	0	1000
Water	0	8200	8200	0
Total	1000	8200	8200	1000

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. R-101 has a residence time of 1.17 hr.
7. Stream 11 is composed of a gas phase stream with entrained liquid tars.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase
SS Superheated Steam
SR Superheated Steam Recycle

Reference Drawings:

Input/Output Diagrams
00-A-022
Block Flow Diagrams
00-A-023
Process Flow Diagrams
01-A-024
02-A-024

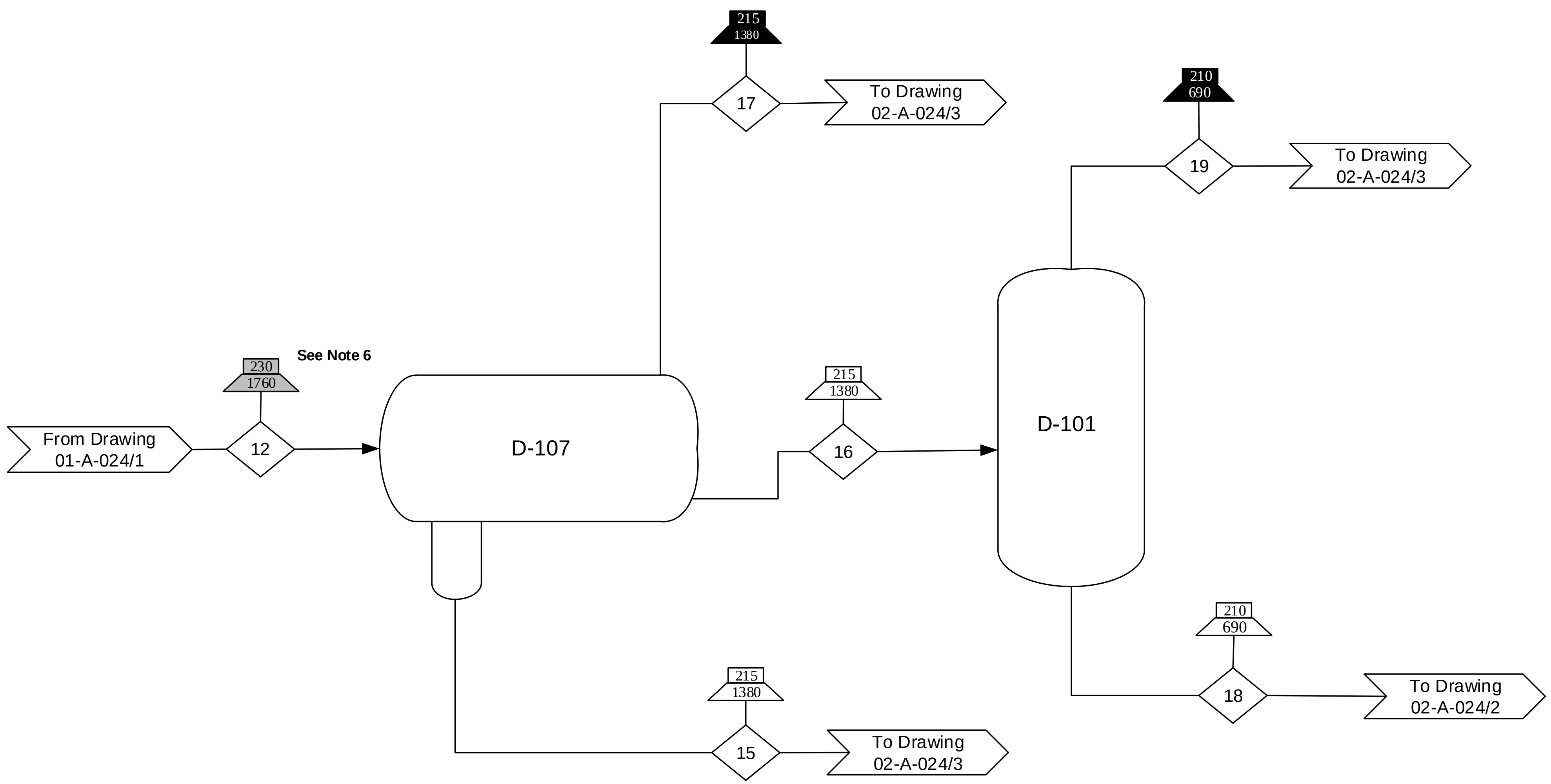
Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design - Thermal Cracking Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	01-A-024/2	0

D-101
Flash 1
Height= 5.8 m
Diameter= 1.4 m

D-107
Acetic Flash 1
Length= 1.8 m
Diameter= 0.5 m



Component/Stream (kg/min)	12	15	16	17	18	19
C1-C50	1000	0	0	0	0	0
C1-C8	0	0	0	210	0	9
C7-C50	0	0	780	0	770	0
Acetic Acid	0	3	0	Trace	0	0
Propionic Acid	0	1	0	0	0	0
Total	1000	4	780	210	770	9

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Stream 12 is composed of an aqueous and organic three phase stream.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°C) Indicator, Liquid/Solid

Pressure (kPa) Indicator, Liquid/Solid

Temperature (°C) Indicator, Gas

Pressure (kPa) Indicator, Gas

Temperature (°C) Indicator, Two Phase

Pressure (kPa) Indicator, Two Phase

Reference Drawings:

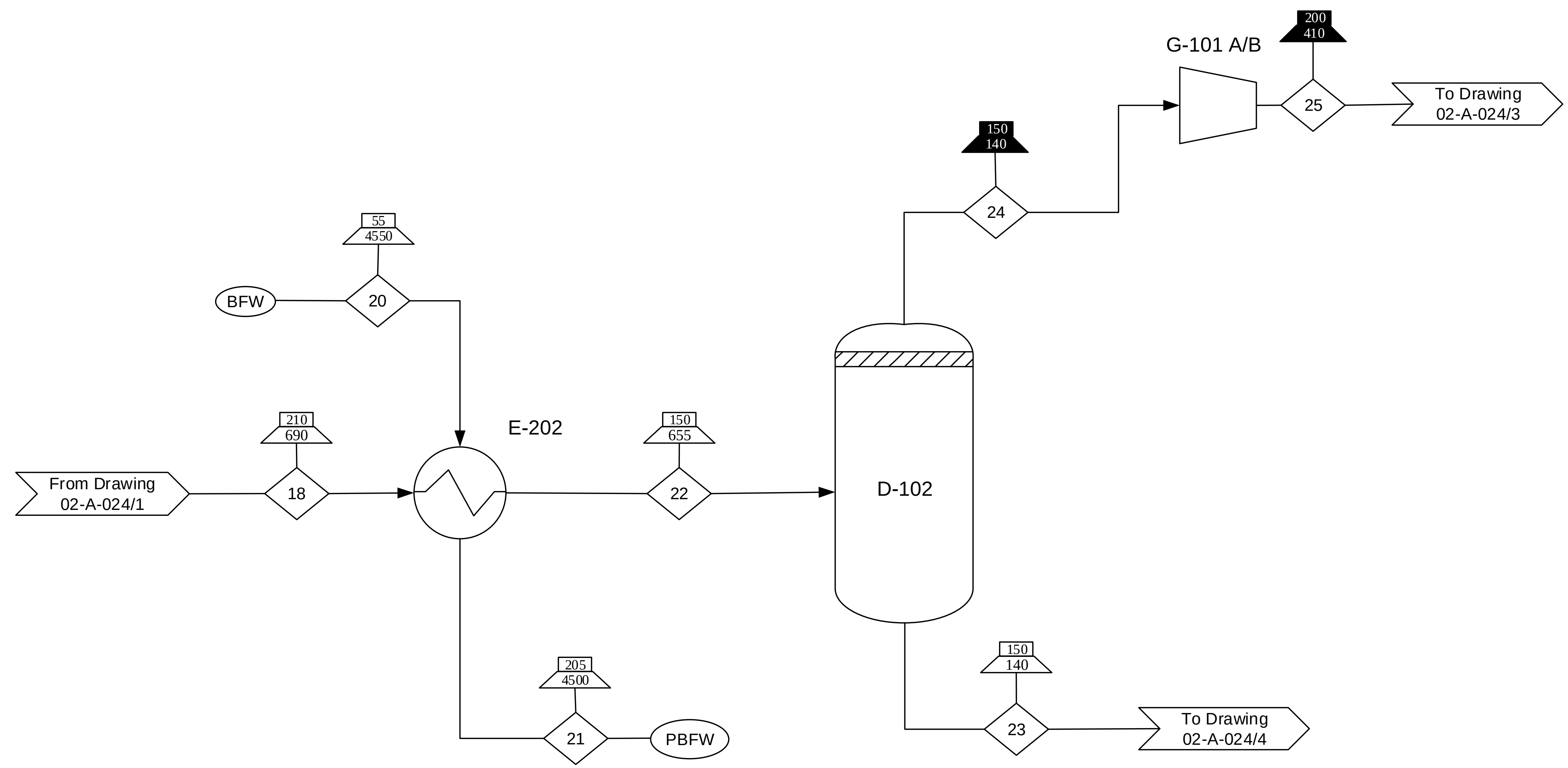
Input/Output Diagram
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
01-A-024
02-A-024

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design-Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	02-A-024/1	0

D-102	E-202 A/B	G-101 A/B
Flash 2	Flash 2 Cooler	Flash 2 Compressor
Height= 5.3 m	Area= 170 m^2	Power= 17 kW
Diameter= 1.4 m	Duty= 2700 kW	

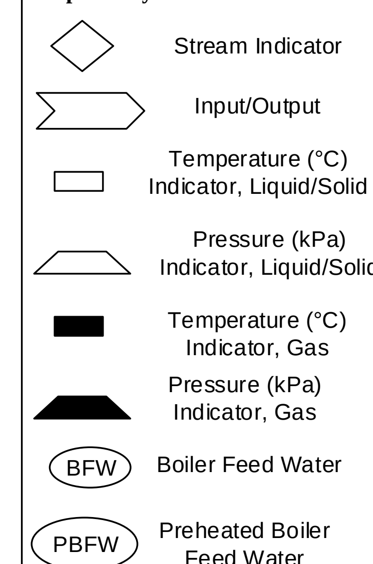


Component/Stream (kg/min)	18	20	21	22	23	24	25
C1-C8	0	0	0	0	0	20	9
C7-C50	770	0	0	770	770	0	0
Water	0	85	85	0	0	0	0
Total	770	85	85	770	770	20	9

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagrams
00-A-022
Block Flow Diagrams
00-A-023
Process Flow Diagrams
02-A-024

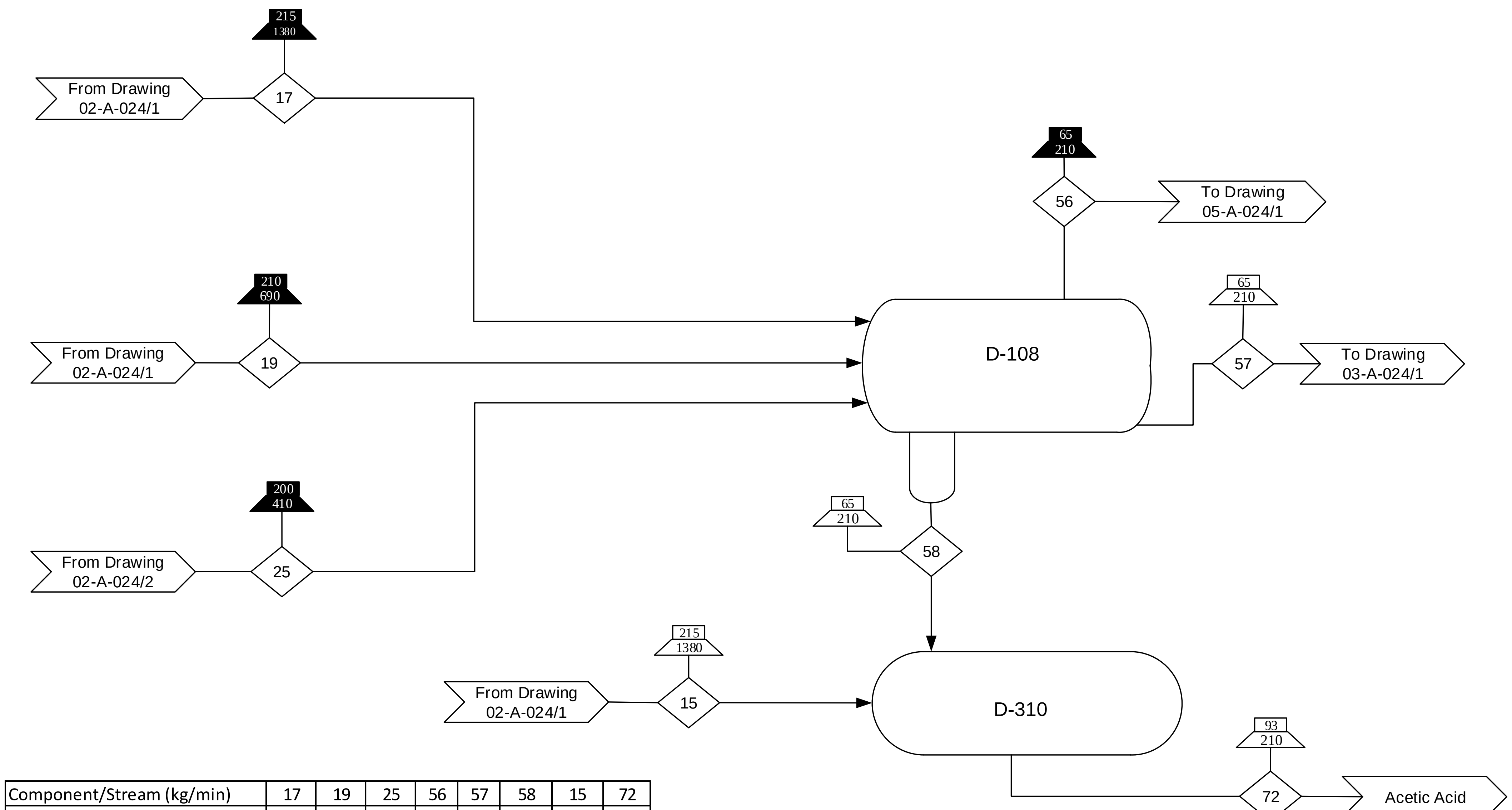
Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design-Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	02-A-024/2	0

D-108
Acetic Flash 2
Height= 3.4 m
Diameter= 0.8 m

D-310
Acetic Acid Drum
Height= 1.2 m
Diameter= 0.3 m



Component/Stream (kg/min)	17	19	25	56	57	58	15	72
C1-C8	210	9	9	0	0	0	0	0
C1-C6	0	0	0	170	0	0	0	0
C6-C8	0	0	0	0	54	0	0	0
Water	0	0	0	0	0	0	0	0
Acetic Acid	0	Trace	Trace	Trace	0	1	3	4
Propionic Acid	0	Trace	Trace	0	0	Trace	1	1
Total	210	9	9	170	54	1	4	5

Notes

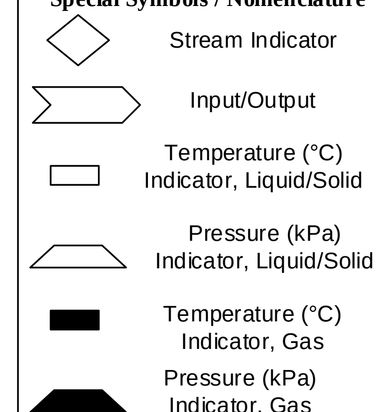
1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



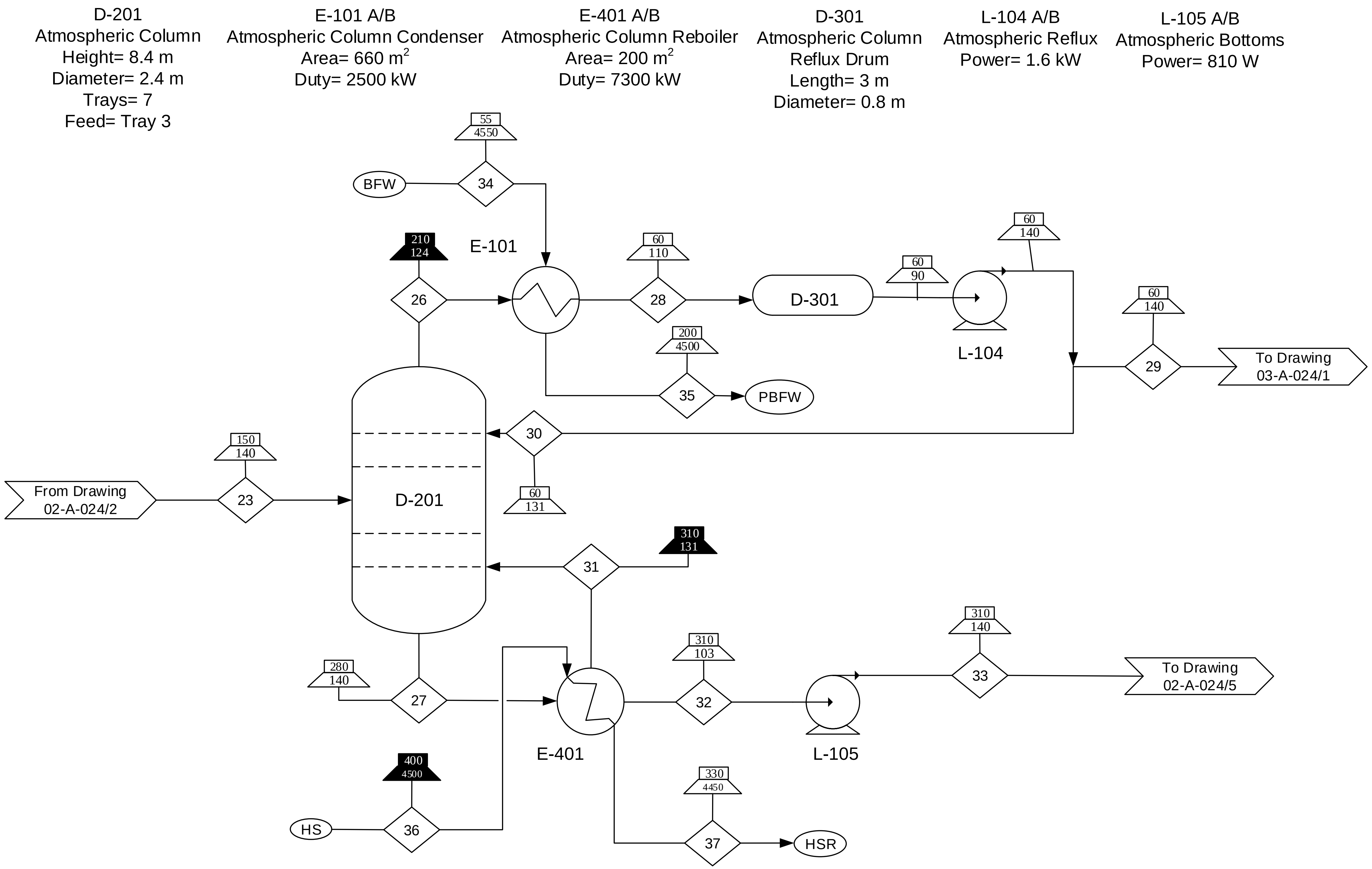
Reference Drawings:

Input/Output Diagram
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
02-A-024
03-A-024
05-A-024

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design-Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	02-A-024/3	0



Component/Stream (kg/min)	23	26	27	28	29	30	31	32	33	34	35	36	37
C7-C12	0	180	0	180	170	13	0	0	0	0	0	0	0
C7-C50	770	0	1450	0	0	0	860	0	0	0	0	0	0
C13-C50	0	0	0	0	0	0	0	590	590	0	0	0	0
Water	0	0	0	0	0	0	0	0	0	78	78	2540	2540
Total	770	180	1450	180	170	13	860	590	590	78	78	2540	2540

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- HS: High Pressure Steam
- HSR: High Pressure Steam Condensate
- BFW: Boiler Feed Water
- PBFW: Preheated Boiler Feed Water

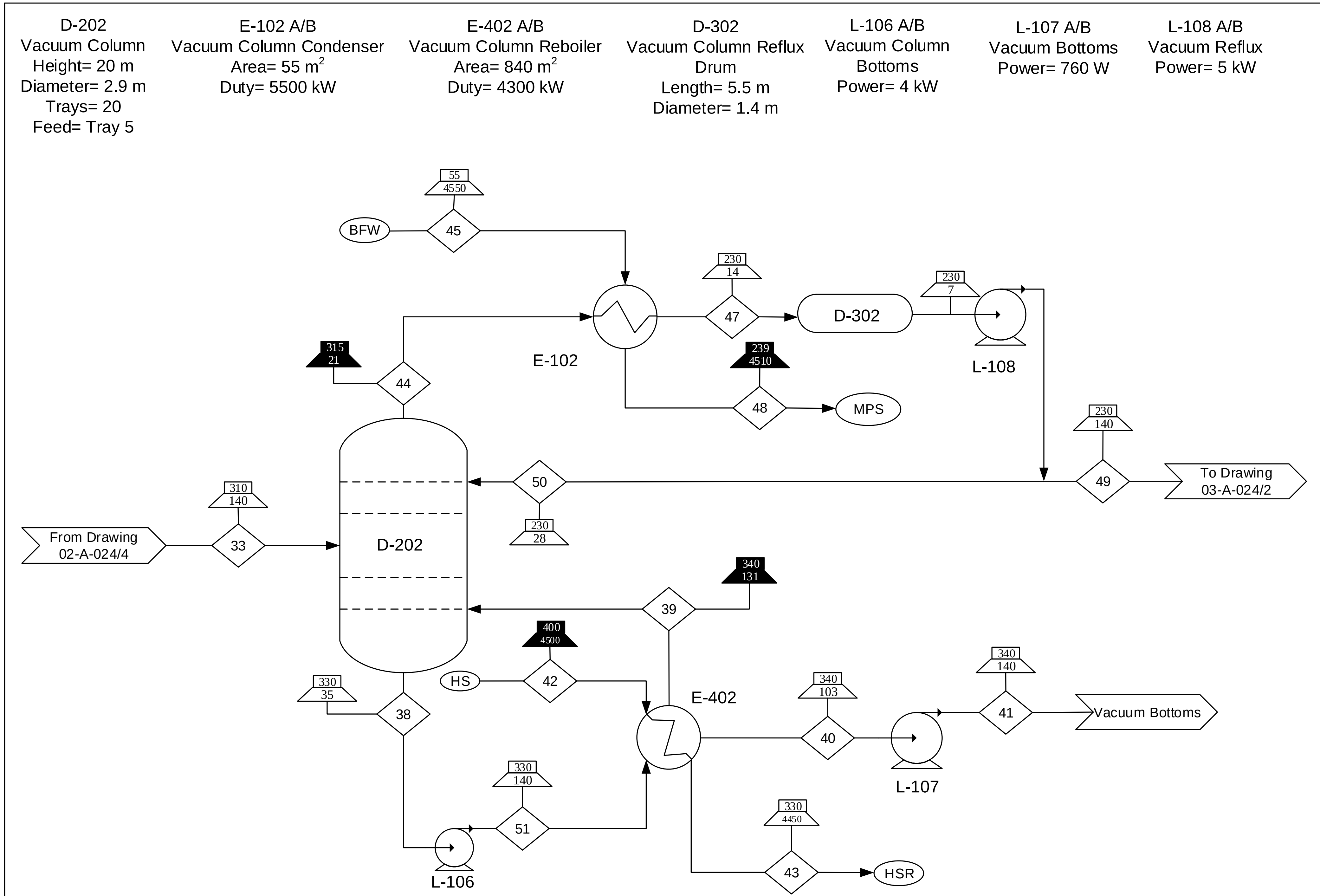
Reference Drawings:

Input/Output Diagram
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
02-A-024
03-A-024

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design-Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	02-A-024/4	0

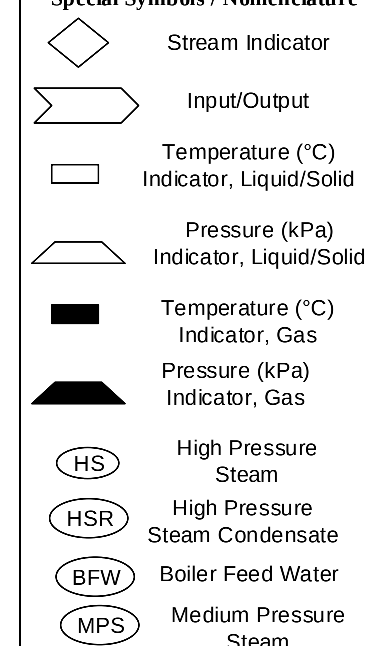


Component/Stream (kg/min)	33	38	39	40	41	42	43	44	45	46	47	48	49	50	51
C12-C50	590	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C12-C30	0	0	0	0	0	0	0	770	0	770	770	0	320	430	0
C30-C50	0	1000	730	1000	280	0	0	0	0	0	0	0	0	0	1000
Water	0	0	0	0	0	1500	1500	0	170	0	0	170	0	0	0
Total	590	1000	730	1000	280	1500	1500	770	170	770	770	170	320	430	1000

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagrams
00-A-022
Block Flow Diagrams
00-A-023
Process Flow Diagrams
02-A-024
03-A-024
06-A-024

Drawing Type
Process Flow Diagram

Title

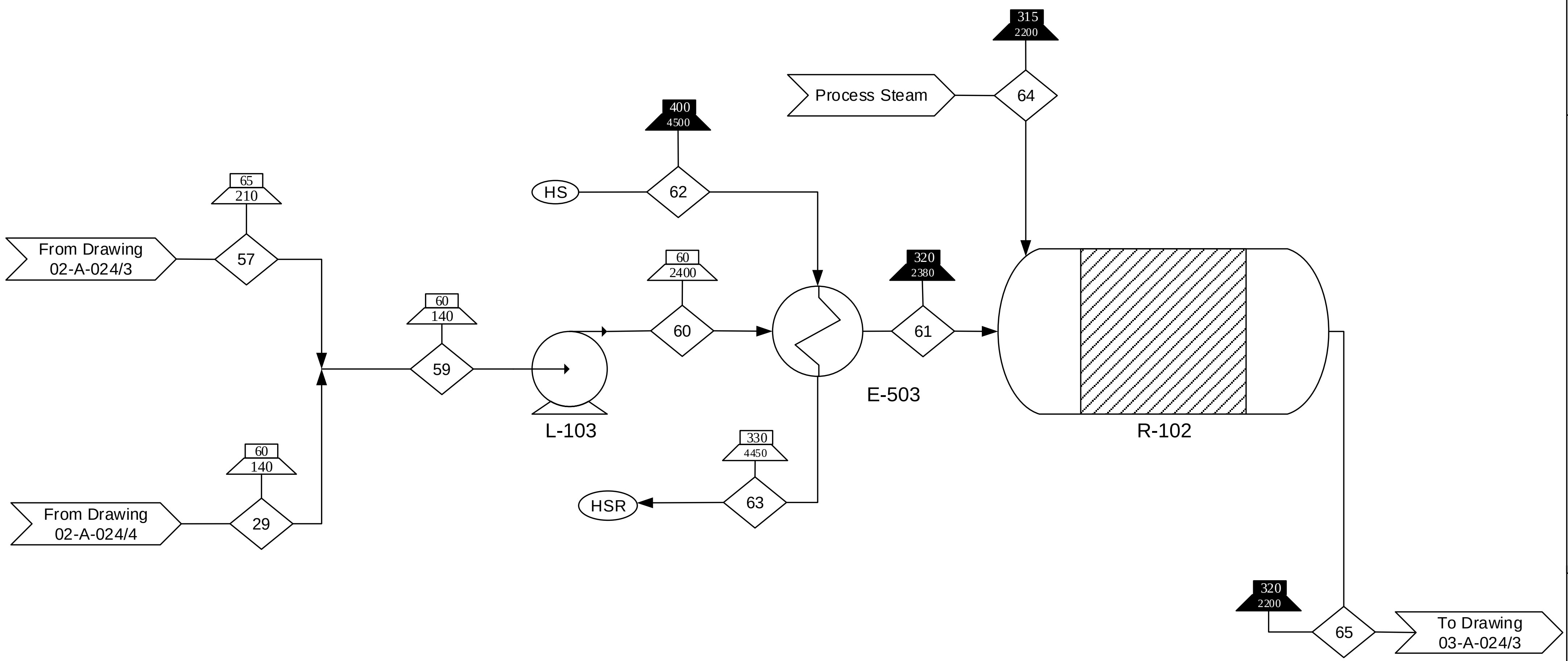
Biorefinery Base Design-Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	02-A-024/5	0

R-102 A/B
Naphtha Decarboxylation Reactor
Diameter= 2.9 m
Length= 17 m
Catalyst= 220 m^3

E-503 A/B
Naphtha Decarbox Heater
Area= 43 m^2
Duty= 3700 kW

L-103 A/B
PreNaphtha Decarbox Pump
Power= 17 kW



Component/Stream (kg/min)	29	57	59	60	61	62	63	64	65
C6-C8	0	54	0	0	0	0	0	0	0
C7-C12	170	0	0	0	0	0	0	0	0
C6-C12	0	0	220	220	220	0	0	0	0
C1-C12	0	0	0	0	0	0	0	0	230
Water	0	0	0	0	0	1300	1300	7	0
Total	170	54	220	220	220	1300	1300	7	230

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
HS High Pressure Steam
HSR High Pressure Steam Condensate

Reference Drawings:

Input/Output Diagram
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
02-A-024
03-A-024

Drawing Type
Process Flow Diagram

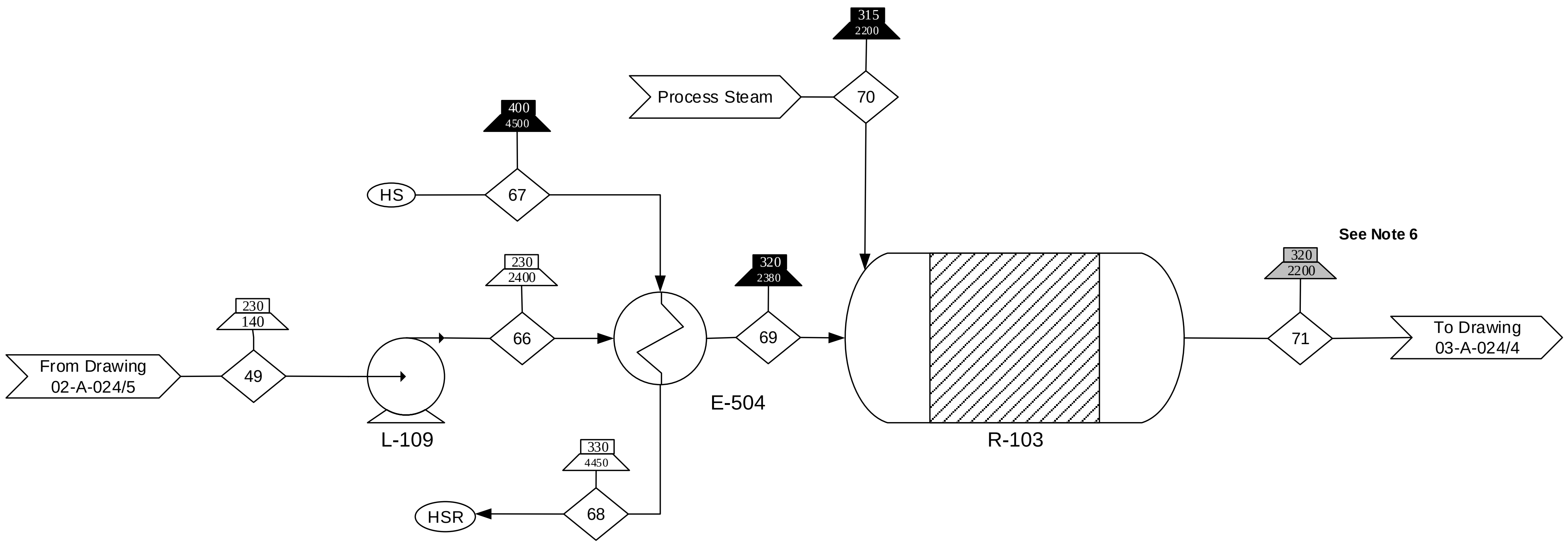
Title
Biorefinery Base Design–Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	03-A-024/1	0

R-103 A/B
Diesel Decarboxylation Reactor
Diameter= 3.2 m
Length= 19 m
Catalyst= 310 m^3

E-504 A/B
Diesel Decarbox Heater
Area= 41 m^2
Duty= 1800 kW

L-109 A/B
Pre Diesel Decarbox Pump
Power= 29 kW



Component/Stream (kg/min)	49	66	67	68	69	70	71
C12-C30	320	320	0	0	320	0	0
C1-C30	0	0	0	0	0	0	330
Water	0	0	640	640	0	10	0
Total	320	320	640	640	320	10	330

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 71 is composed of a liquid gas two phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase
HS High Pressure Steam
HSR High Pressure Steam Condensate

Reference Drawings:

Input/Output Diagram
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
02-A-024
03-A-024

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	03-A-024/2	0

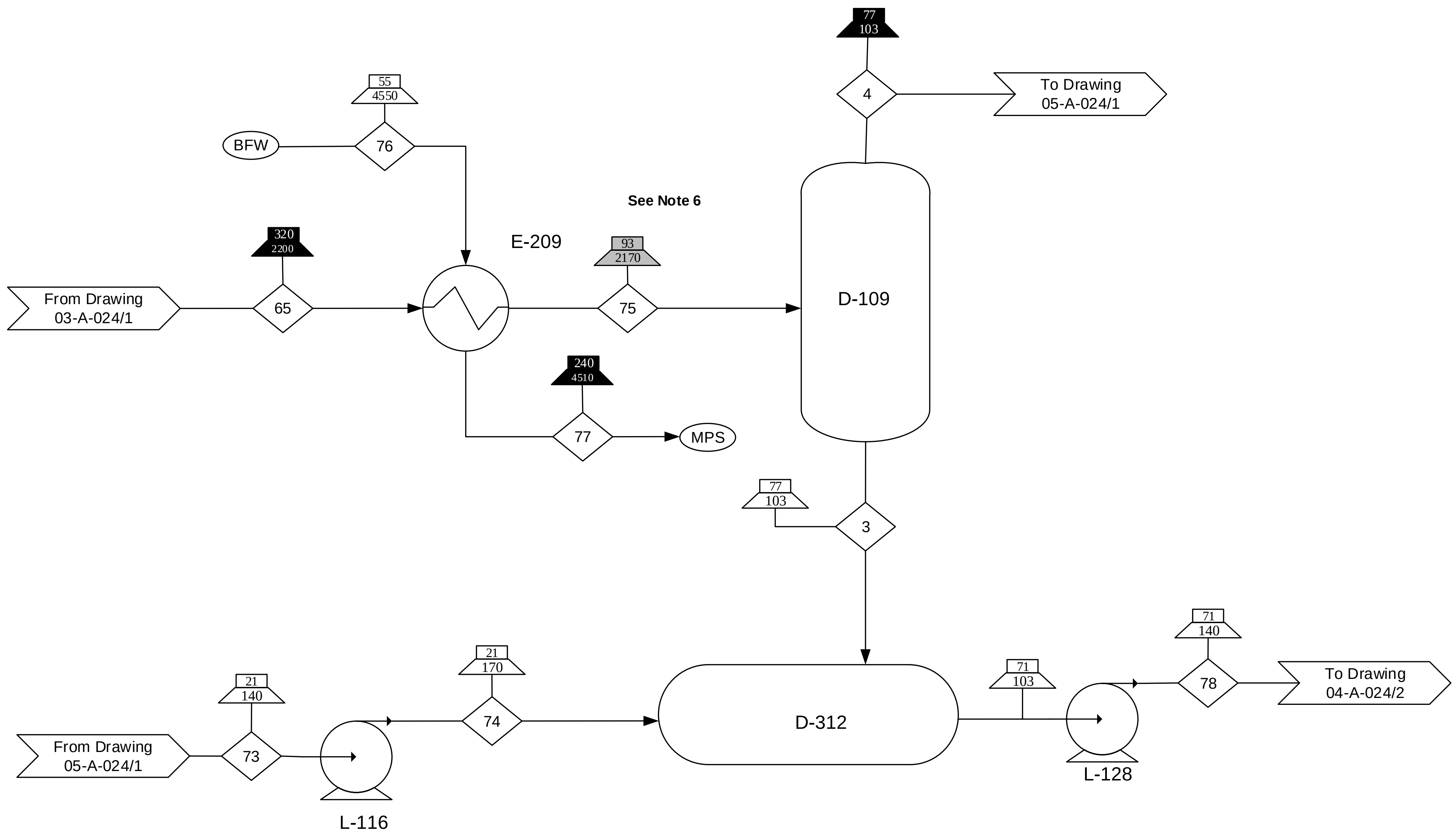
D-109
Flash 7
Height= 2.7 m
Diameter= 0.7 m

E-209 A/B
Post Naphtha Decarbox Cooler
Area = 74 m^2
Duty = 3600 kW

D-312
Flash 7 Drum
Height = 3.2 m
Diameter = 1.1 m

L-116 A/B
Flash 5 Pump
Power = 48 W

L-128 A/B
Flash 7 Pump
Power = 250 W

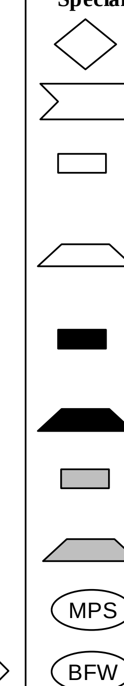


Component/Stream (kg/min)	65	73	74	75	76	77	3	4	78
C1-C12	230	0	0	230	0	0	0	0	0
C6-C9	0	23	23	0	0	0	0	0	200
C1-C4	0	0	0	0	0	0	0	54	0
C4-C12	0	0	0	0	0	0	180	0	0
Water	0	0	0	0	91	91	0	0	0
Total	230	23	23	230	91	91	180	54	200

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 75 is composed of a liquid and gas two phase stream.

Special Symbols / Nomenclature



- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- Temperature (°C) Indicator, Two Phase
- Pressure (kPa) Indicator, Two Phase
- MPS: Medium Pressure Steam
- BFW: Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
03-A-024
04-A-024
05-A-024

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design–Decarboxylation Section

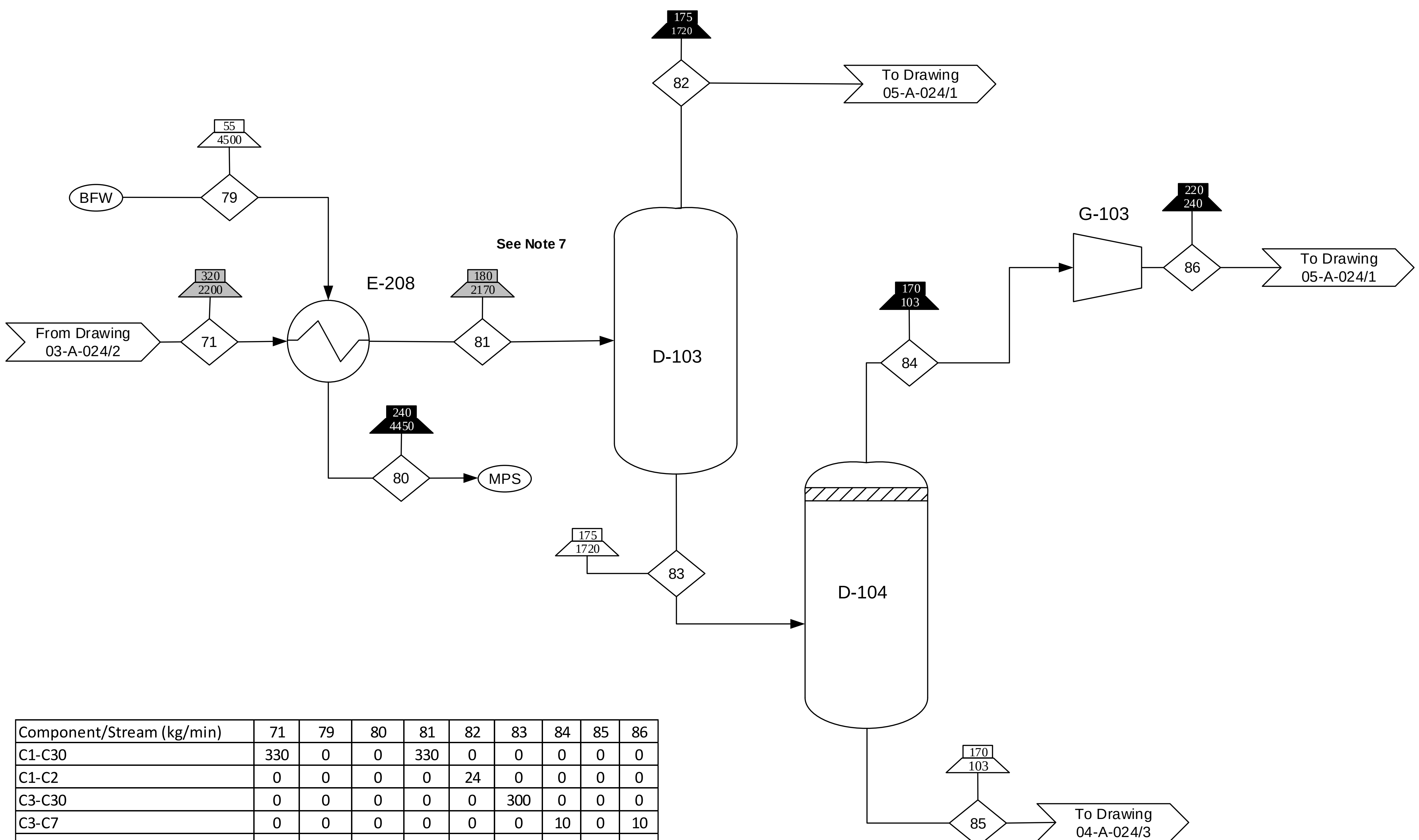
By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	03-A-024/3	0

D-103
Flash 3
Height= 4.9 m
Diameter= 1.2 m

D-104
Flash 4
Height= 4.7 m
Diameter= 1.2 m

E-208 A/B
Post Diesel Decarbox Cooler
Area= 33 m^2
Duty= 2800 kW

G-103 A/B
Flash 5 Compressor
Power= 15 kW



Component/Stream (kg/min)	71	79	80	81	82	83	84	85	86
C1-C30	330	0	0	330	0	0	0	0	0
C1-C2	0	0	0	0	24	0	0	0	0
C3-C30	0	0	0	0	0	300	0	0	0
C3-C7	0	0	0	0	0	0	10	0	10
C8-C30	0	0	0	0	0	0	0	290	0
Water	0	68	68	0	0	0	0	0	0
Total	330	68	68	330	24	300	10	290	10

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
7. Streams 71 and 81 are composed of a liquid and gas two phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase
MPS Medium Pressure Steam
BFW Boiler Feed Water

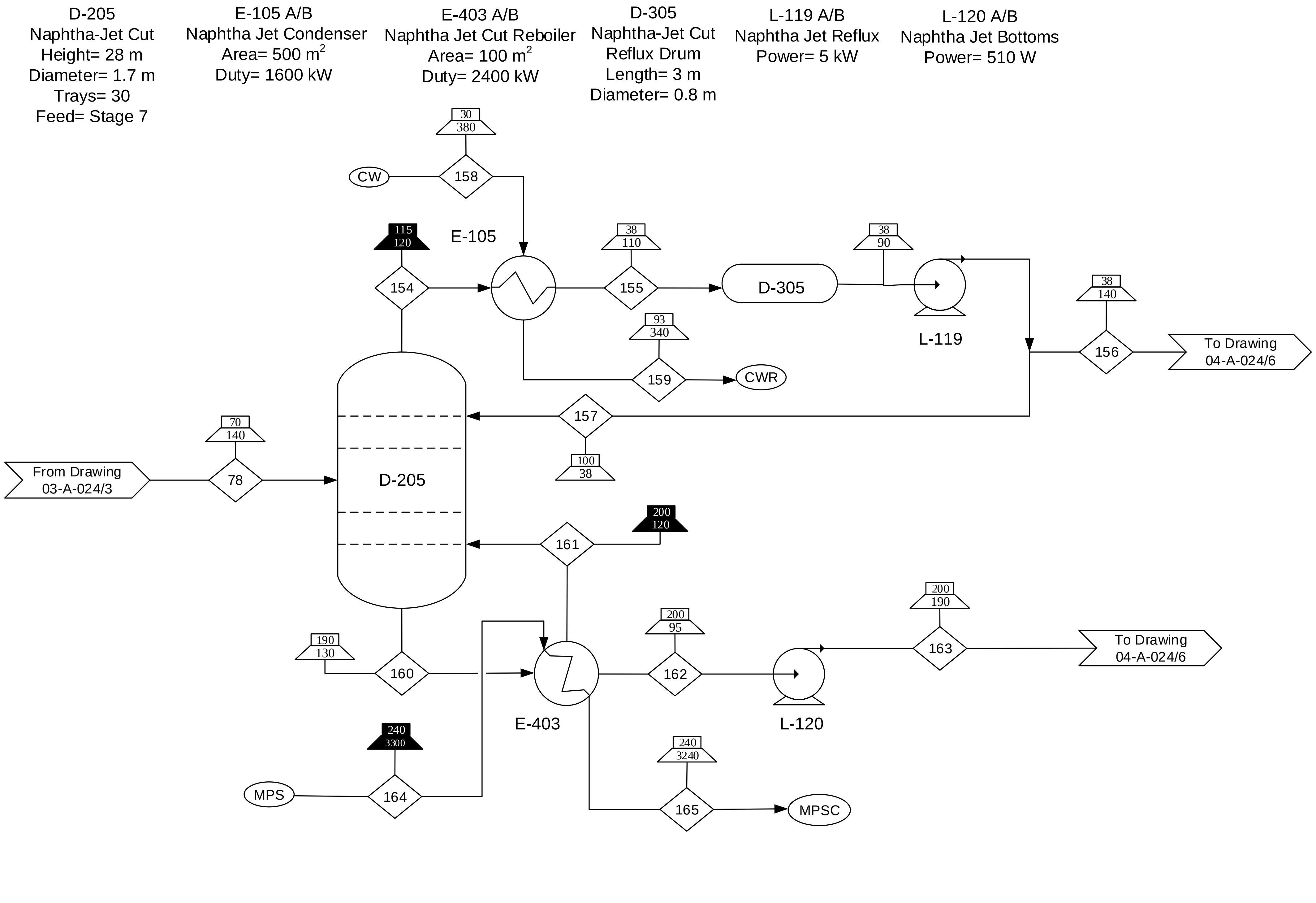
Reference Drawings:

Process Flow Diagrams
03-A-024
04-A-024
05-A-024

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	03-A-024/4	0



Component/Stream (kg/min)	78	154	155	156	157	158	159	160	161	162	163	164	165
C7-C12	200	0	0	0	0	0	0	0	0	0	0	0	0
C7-C9	0	150	150	64	82	0	0	0	0	0	0	0	0
C9-C12	0	0	0	0	0	0	0	330	190	140	140	0	0
Water	0	0	0	0	0	150	150	0	0	0	0	82	82
Total	200	150	150	64	82	150	150	330	190	140	140	82	82

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
MPS Medium Pressure Steam
MPSC Medium Pressure Steam Condensate
CW Cooling Water
CWR Cooling Water Recycle

Reference Drawings:

Input/Output Diagram
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
03-A-024
04-A-024

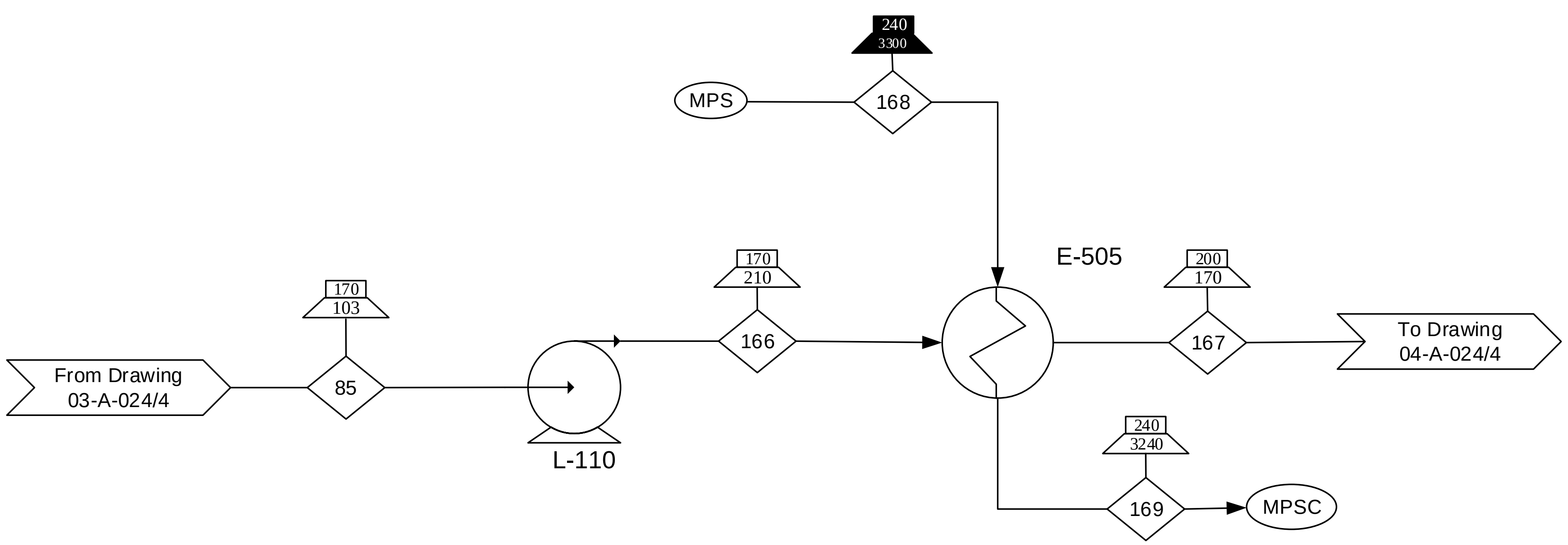
Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	04-A-024/2	0

E-505 A/B
Pre Jet Diesel Cut Heat
Area = 22 m^2
Duty = 540 kW

L-110 A/B
Pre Jet Diesel Cut Heat Pump
Power = 1 kW



Component/Stream (kg/min)	85	166	167	168	169
C8-C30	290	290	290	0	0
Water	0	0	0	18	18
Total	290	290	290	18	18

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
MPS Medium Pressure Steam
MPSC Medium Pressure Steam Condensate

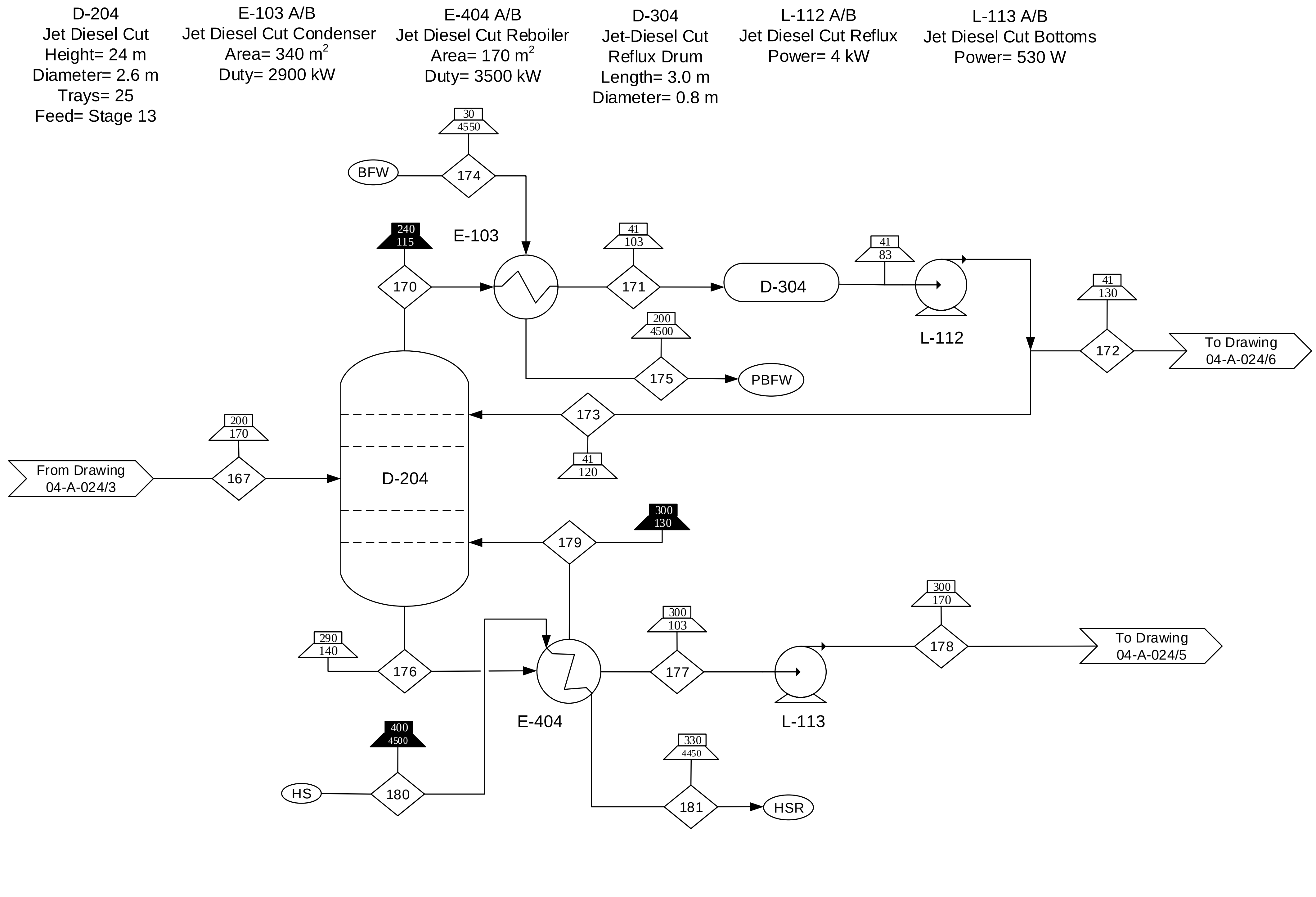
Reference Drawings:

Input/Output Diagram
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
03-A-024
04-A-024

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design– Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	04-A-024/3	0



Component/Stream (kg/min)	167	170	171	172	173	174	175	176	177	178	179	180	181
C8-C30	290	0	0	0	0	0	0	0	0	0	0	0	0
C8-C15	0	190	190	73	110	0	0	0	0	0	0	0	0
C16-C30	0	0	0	0	0	0	0	860	220	200	640	0	0
Water	0	0	0	0	0	89	89	0	0	0	0	1200	1200
Total	290	190	190	73	110	89	89	860	220	220	640	1200	1200

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
HS High Pressure Steam
HSR High Pressure Steam Condensate
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

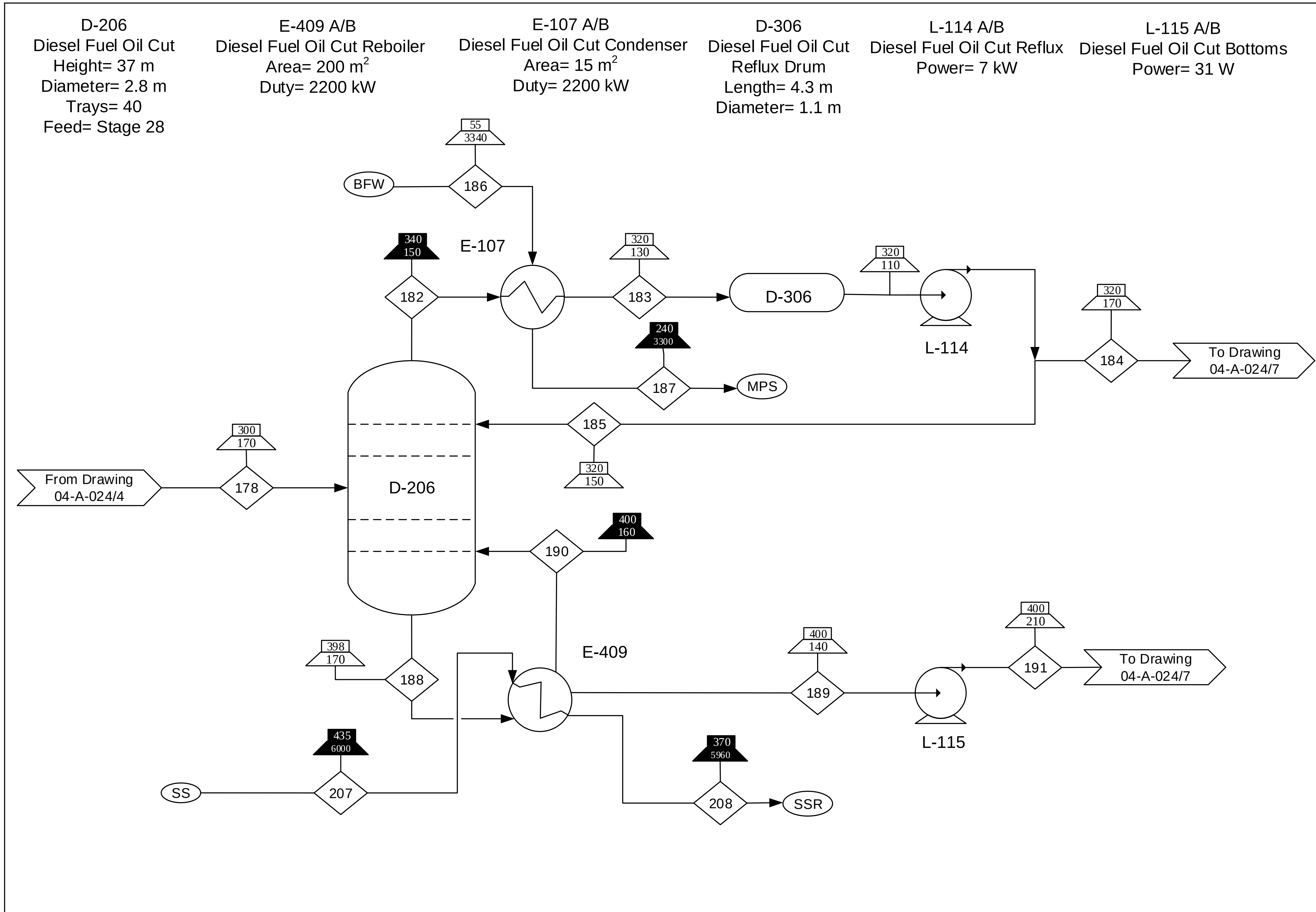
Reference Drawings:

Input/Output Diagam
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
04-A-024

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design– Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	04-A-024/4	0



Component/Stream (kg/min)	178	182	183	184	185	186	187	188	189	190	191	207	208
C16-C30	220	0	0	0	0	0	0	0	0	0	0	0	0
C16-C21	0	380	380	210	160	0	0	0	0	0	0	0	0
C22-C30	0	0	0	0	0	0	0	640	5	640	4	0	0
Water	0	0	0	0	0	54	54	0	0	0	0	760	760
Total	220	380	380	210	160	54	54	640	5	640	4	760	760

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°C) Indicator, Liquid/Solid

Pressure (kPa) Indicator, Liquid/Solid

Temperature (°C) Indicator, Gas

Pressure (kPa) Indicator, Gas

MPS Medium Pressure Steam

BFW Boiler Feed Water

SS Superheated Steam

SSR Superheated Steam Recycle

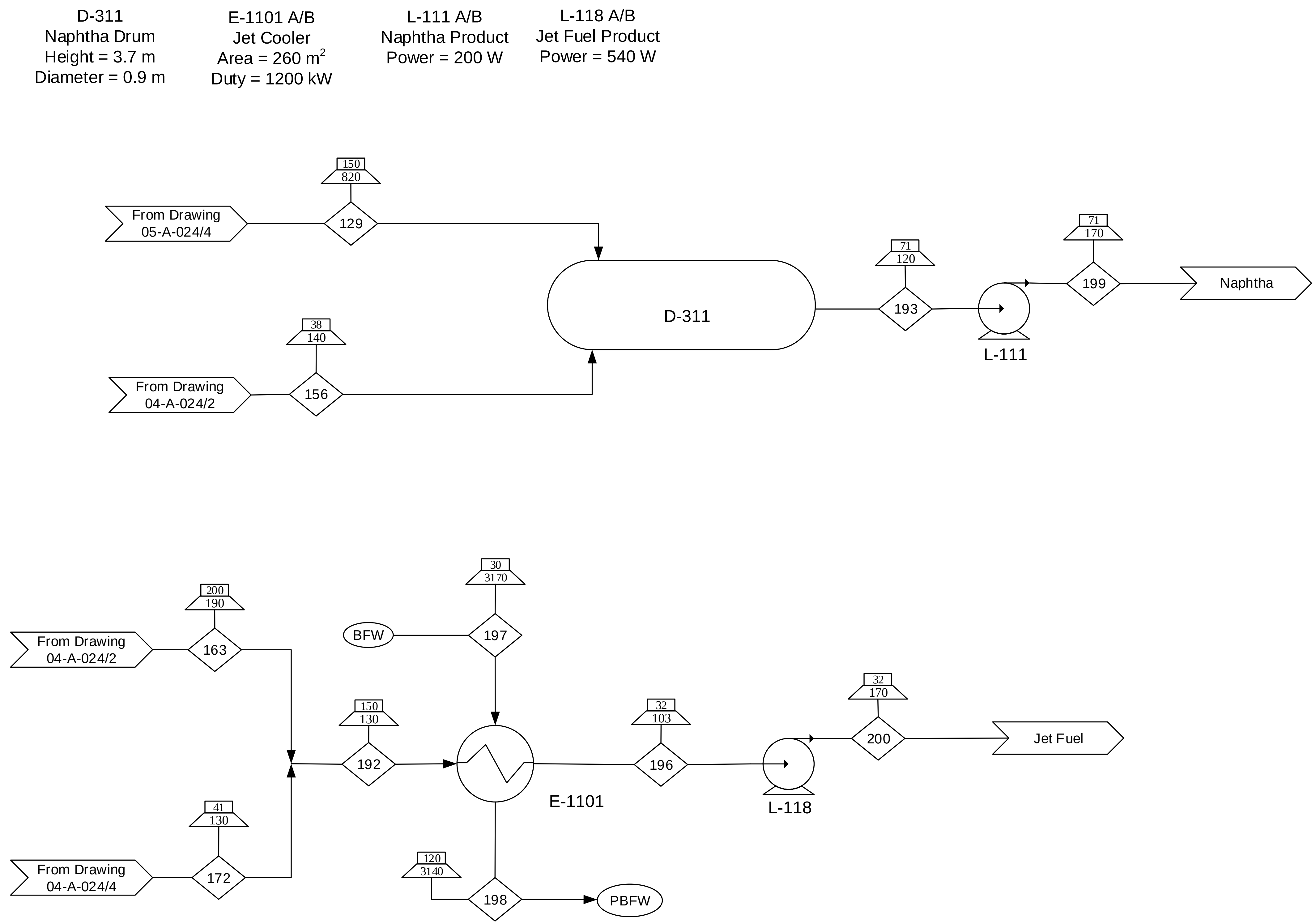
Reference Drawings:

Input/Output Diagram
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
04-A-024

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	04-A-024/5	0



Component/Stream (kg/min)	129	156	163	172	192	193	196	197	198	199	200
Naphtha Product	64	64	0	0	0	130	0	0	0	130	0
Jet Fuel Product	0	0	140	73	210	0	210	0	0	0	210
Water	0	0	0	0	0	0	0	110	110	0	0
Total	64	64	140	73	210	130	210	110	110	130	210

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
04-A-024
05-A-024

Drawing Type
Process Flow Diagram

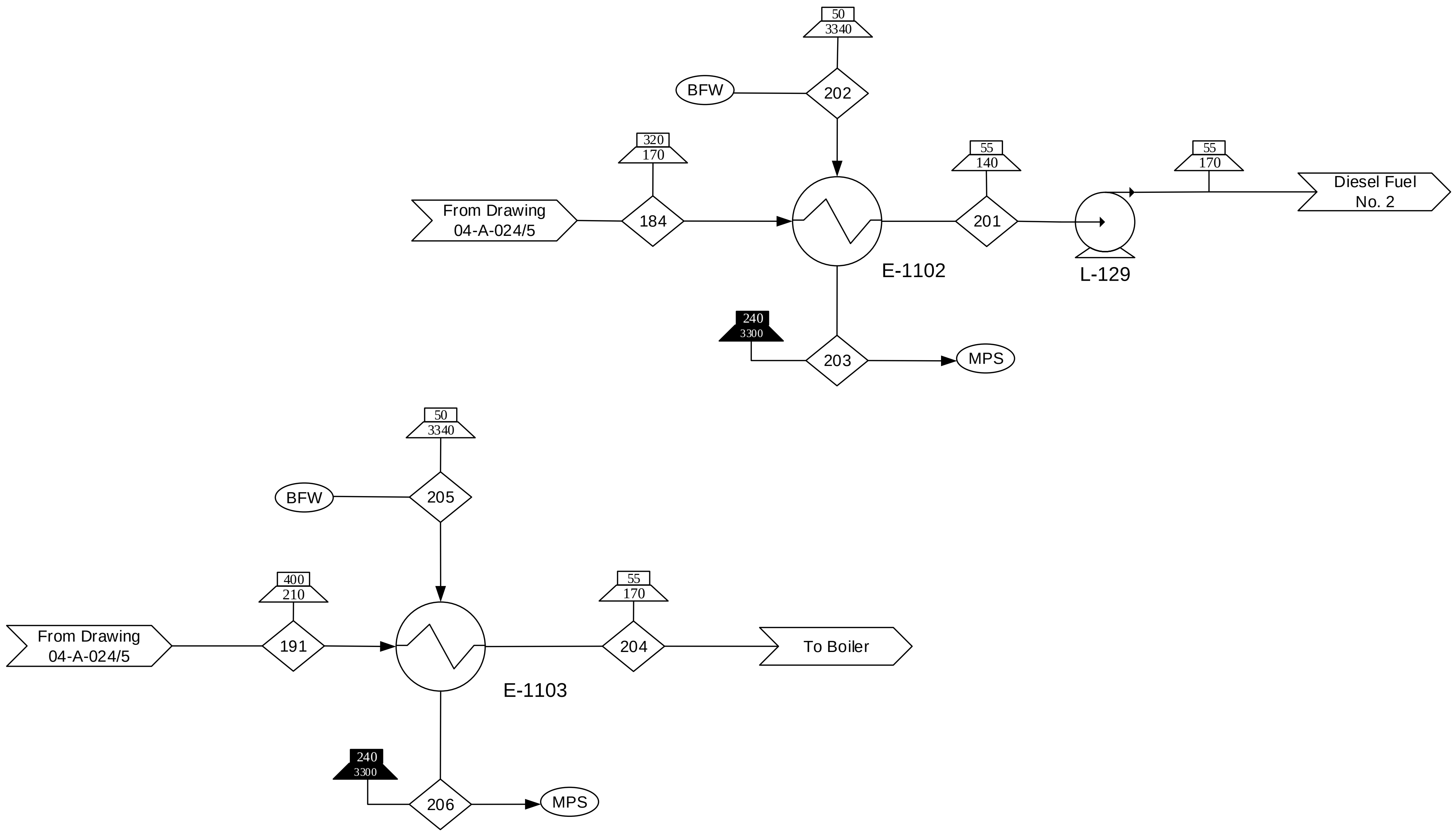
Title
Biorefinery Base Design– Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	04-A-024/6	0

E-1102 A/B
Diesel Cooler
Area = 130 m^2
Duty = 3000 kW

E-1103 A/B
Fuel Oil Cooler
Area = 6 m^2
Duty = 80 kW

L-129 A/B
Diesel Product
Power = 330 W



Component/Stream (kg/min)	184	191	201	202	203	204	205	206
Diesel Fuel No. 2 Product	210	0	210	0	0	0	0	0
Fuel Oil No. 5 Product	0	4	0	0	0	4	0	0
Water	0	0	0	73	73	0	2	2
Total	210	4	210	73	73	4	2	2

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
MPS Medium Pressure Steam
BFW Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
04-A-024

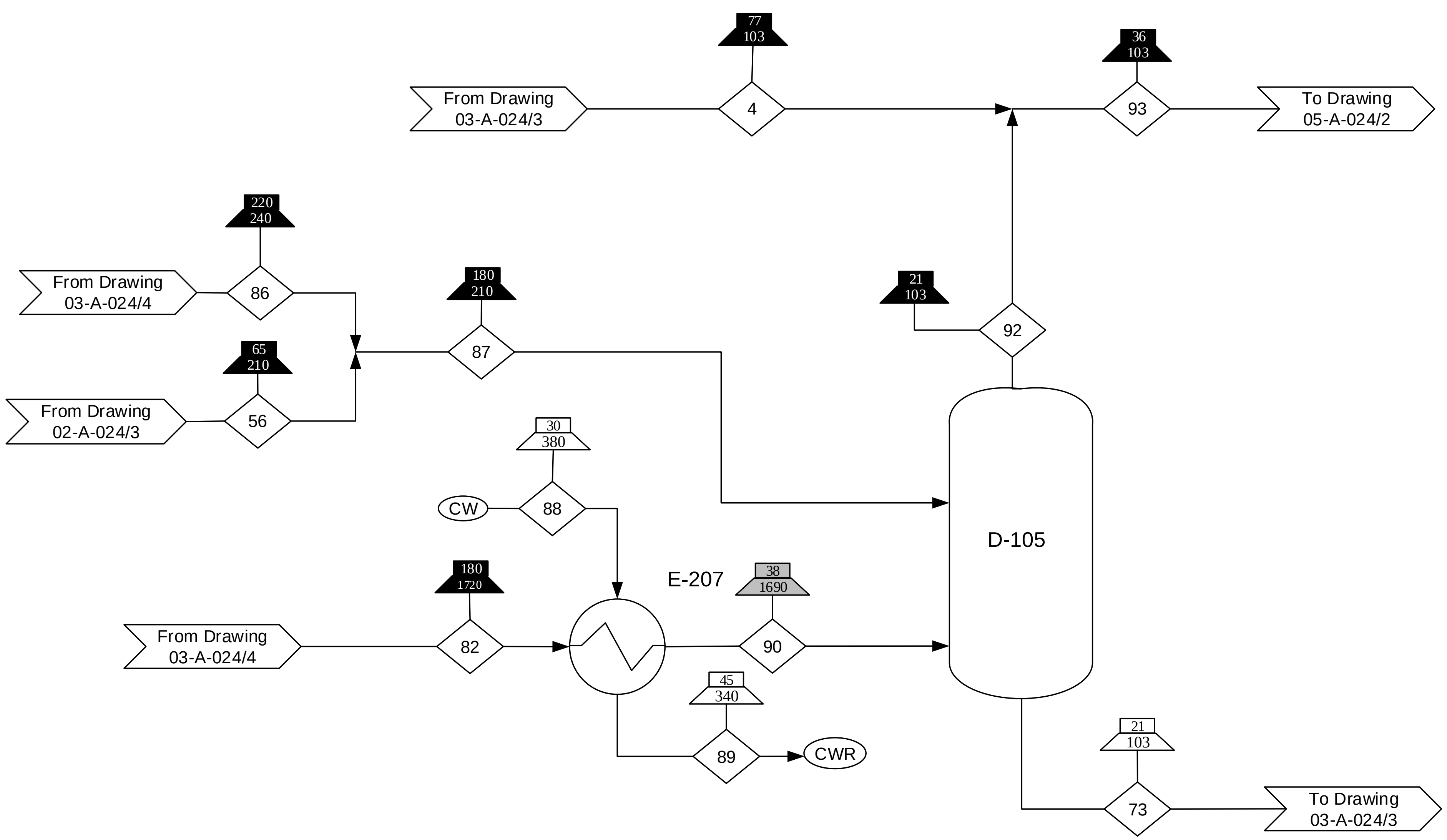
Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	04-A-024/7	0

D-105
Flash 5
Height= 5.4 m
Diameter= 1.4 m

E-207 A/B
Pre-Flash 5 Cooler
Area= 41 m^2
Duty= 400 kW



Component/Stream (kg/min)	4	56	73	82	86	87	88	89	90	92	93
C1-C2	0	0	0	24	0	0	0	0	24	0	0
C3-C7	0	0	0	0	10	0	0	0	0	0	0
C1-C7	0	0	0	0	0	0	0	0	0	0	0
C1-C6	54	170	0	0	0	180	0	0	0	190	240
C6-C7	0	0	23	0	0	0	0	0	0	0	0
Water	0	0	0	0	0	0	38	38	0	0	0
Total	54	170	23	24	10	180	38	38	24	190	240

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase
CW Cooling Water
CWR Cooling Water Recycle

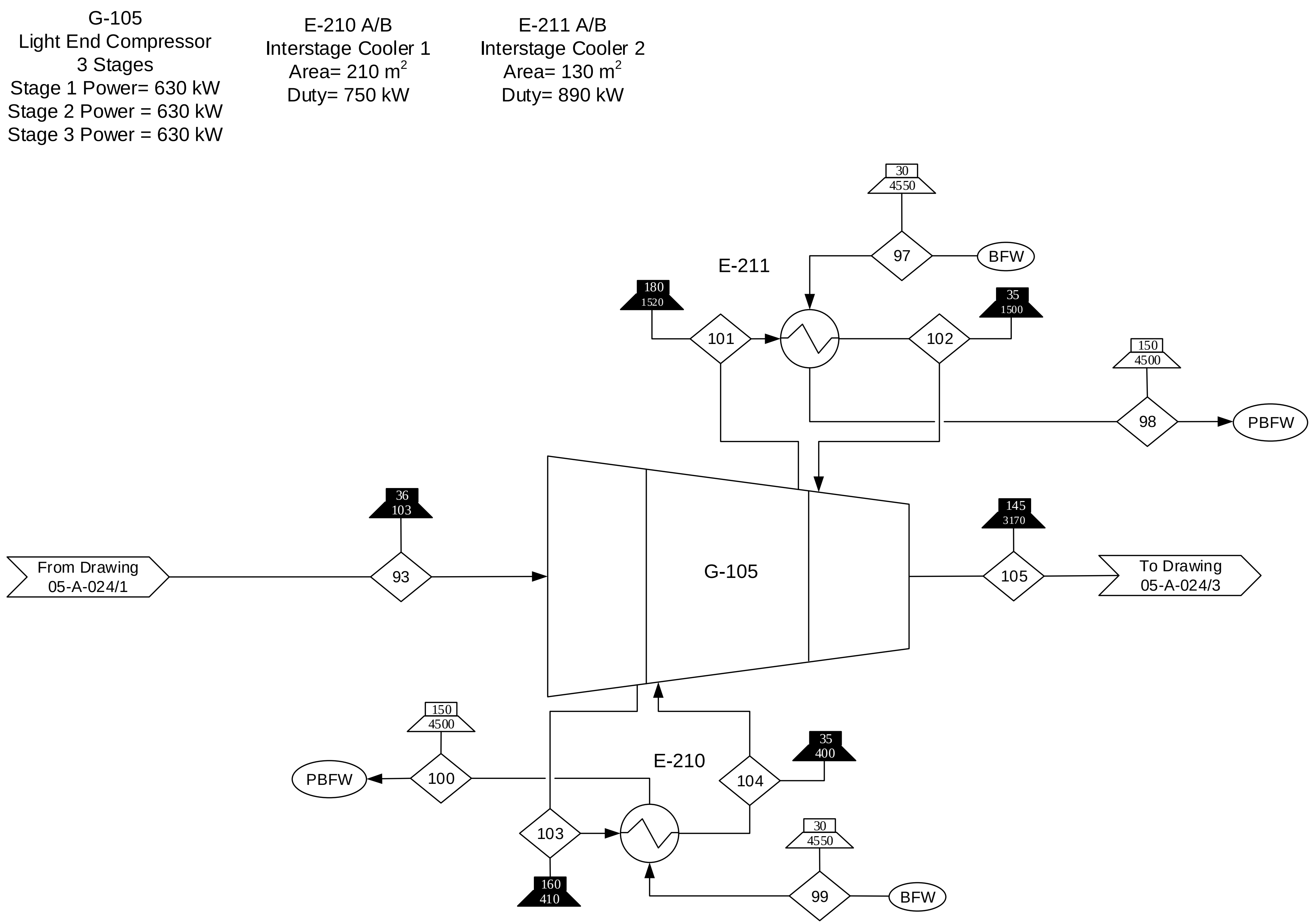
Reference Drawings:

Input/Output Diagram
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
02-A-024
03-A-024
05-A-024

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	05-A-024/1	0

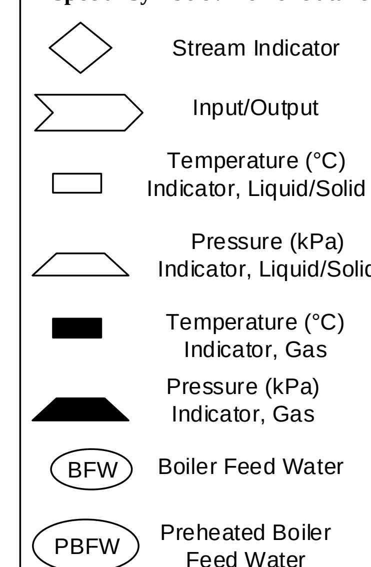


Component/Stream (kg/min)	93	97	98	99	100	101	102	103	104
C1-C6	240	0	0	0	0	240	240	240	240
Water	0	83	83	69	69	0	0	0	0
Total	240	83	83	69	69	240	240	240	240

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



Reference Drawings:

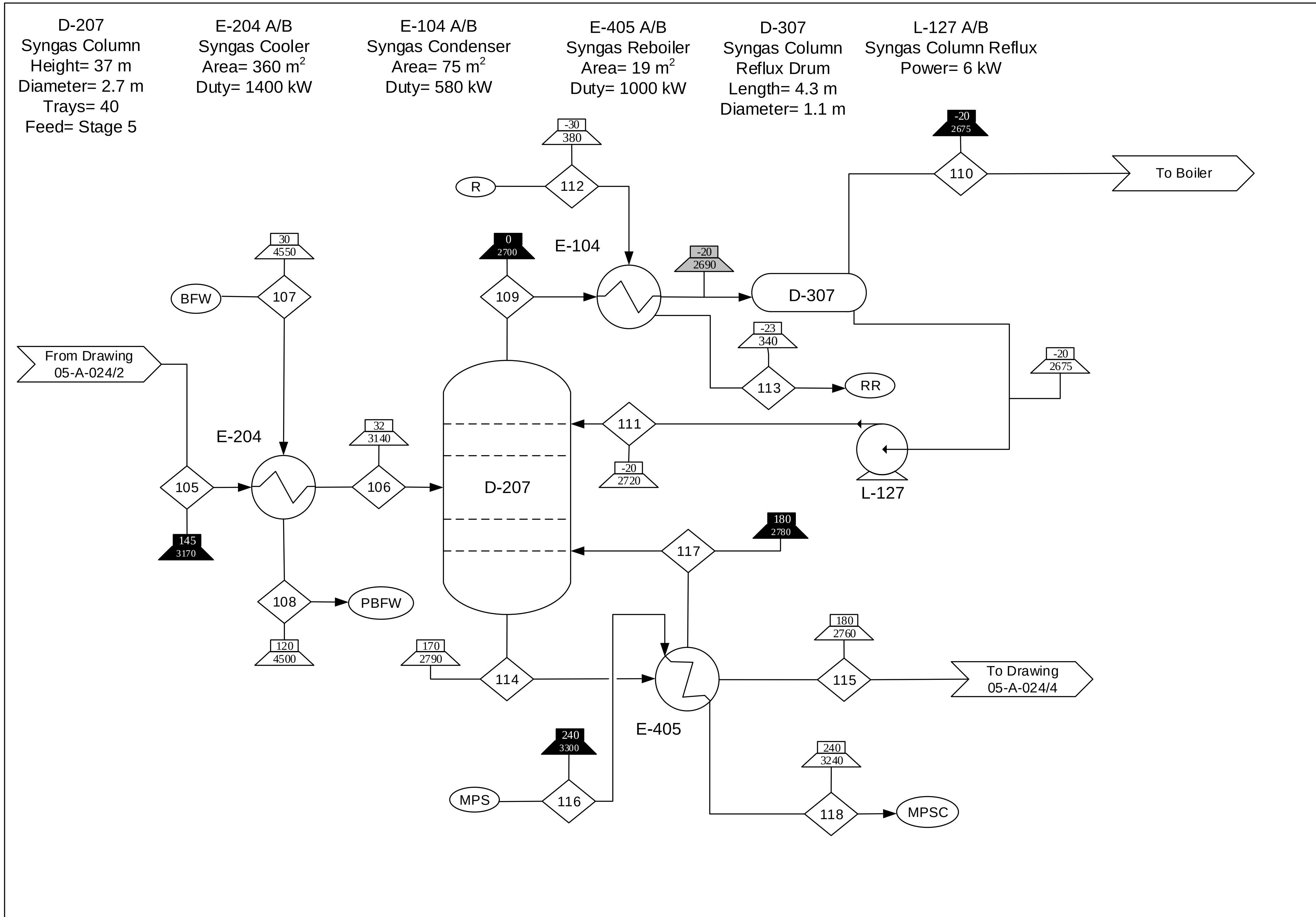
Input/Output Diagram
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
05-A-024

Drawing Type
Process Flow Diagram

Title

Biorefinery Base Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	05-A-024/2	0



Component/Stream (kg/min)	105	106	107	108	109	110	111	112	113	114	115	116	117	118
C1-C6	240	240	0	0	0	0	0	0	0	0	0	0	0	0
C1-C3	0	0	0	0	240	160	77	0	0	0	0	0	0	0
C4-C6	0	0	0	0	0	0	0	0	0	350	82	0	270	0
Water	0	0	130	130	0	0	0	540	540	0	0	34	0	34
Total	240	240	130	130	240	160	77	540	540	350	82	34	270	34

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase
MPS Medium Pressure Steam
MPSC Medium Pressure Steam Condensate
R Refrigerant
RR Refrigerant Return
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

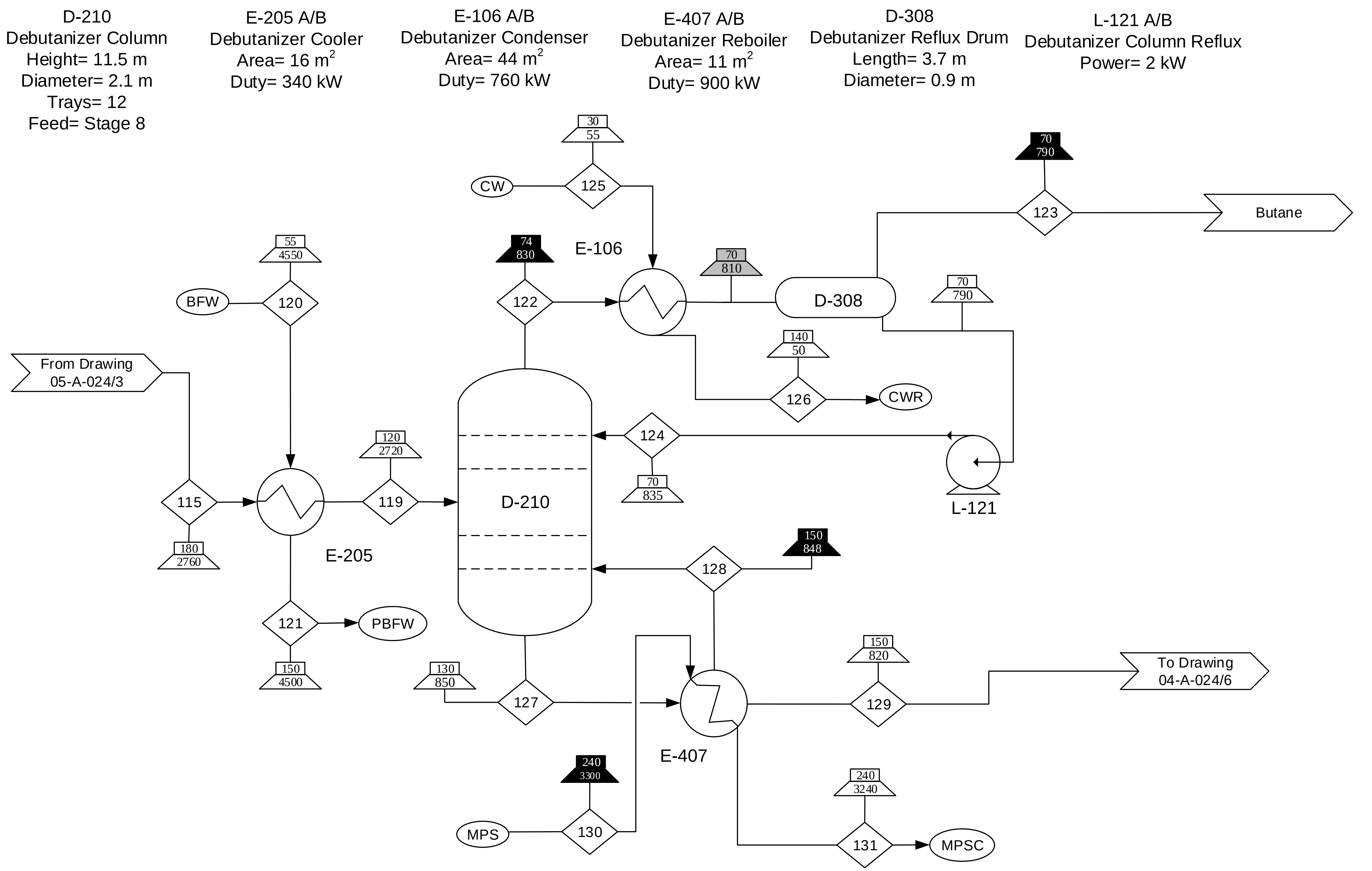
Reference Drawings:

Input/Output Diagram
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
05-A-024

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design– Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	05-A-024/3	0



Component/Stream (kg/min)	115	119	120	121	122	123	124	125	126	127	128	129	130	131
C4-C6	82	82	0	0	0	0	0	0	0	0	0	0	0	0
Butane	0	0	0	0	150	21	130	0	0	0	0	0	0	0
C5-C6	0	0	0	0	0	0	0	0	0	230	160	64	0	0
Water	0	0	32	32	0	0	0	70	70	0	0	0	31	31
Total	82	82	32	32	150	21	130	70	70	230	160	64	31	31

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
5. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- Temperature (°C) Indicator, Two Phase
- Pressure (kPa) Indicator, Two Phase
- MPS Medium Pressure Steam
- MPSC Medium Pressure Steam Condensate
- CW Cooling Water
- CWR Cooling Water Recycle
- BFW Boiler Feed Water
- PBFW Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-022
Block Flow Diagram
00-A-023
Process Flow Diagrams
04-A-024
05-A-024

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design– Light End Processing

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SAB/ 4-24-17	05-A-024/4	0

Chapter IV

A BIOREFINERY BASED ON THE NONCATALYTIC CRACKING OF TRIGLYCERIDE OILS – FATTY ACID RECOVERY DESIGN

The production of additional higher value byproducts can reduce the risk surrounding the economics of producing transportation fuels from triglyceride based oils. One of these alternatives is the extraction and recovery of the short and medium chain fatty acids that are produced during cracking.

The following sections describe how the fatty acid recovery alternative was designed. Section IV.A describes the process design that includes the separation and recovery of the fatty acids from the organic liquid product, along with the desired transportation fuels. Section IV.B reviews the economic assessment that was performed on this alternative while Section IV.C examines the profitability of this process alternative.

IV.A. Process Design

The design provided is specifically based on a feed of soybean oil. However, any triglyceride (TG) oil, unsaturated fatty acid, or carboxylic acid (e.g. lipids) can be used. Differences in the product rates and slight differences in the reaction temperatures are the only expected variations based on feedstock. A 7500 MTPD soybean oil extraction plant can efficiently produce 600,000 m^3/year of crude soybean oil [56]. The typical composition of this soybean oil can be found in Table 42. The crude soybean oil feed, shown in Table 43, can then be noncatalytically cracked into naphtha which is a gasoline blend compound, plus transportation fuel quality kerosene and diesel oils. Kerosene is the primary compound of jet fuel. The flow rates of the most significant products can be found in Table 44. All products produced are in compliance with the fuel ASTM standards. The properties of these streams can be found in Tables 45-47. Other possibilities, not directly addressed in this design are other kerosene products and diesel no. 1.

In addition to the production of transportation fuels, the byproducts of butane, vacuum bottoms, and C2-C11 fatty acids are produced. The flow rates of all byproducts can be found in Table 48, and the ASTM properties of butane can be found in Table 49. All fatty acid streams have a 98% purity. This process also produces two stream that are used as boiler feed for the plant. These streams can be found in Table 50. The input/output diagram (drawing 00-A-010) shows the overall mass balance and mass flow rates of the inputs and outputs to the process.

Catalyst is used in the decarboxylation reactions, and is used to convert the carboxylic acids that are produced during the noncatalytic cracking of the soybean oil into alkanes. The solvent trimethylamine (TMA). TMA is used in the extraction step to remove the fatty acids from the organic liquid product. The amount of catalyst and chemicals used for the process can be found in Table 51, and the utilities required are presented in Table 52.

The process was designed as four core subsystems. The first subsystem consists of the thermal cracking section. In this section the incoming soybean oil is cracked into a three phase product through the use of noncatalytic cracking at high temperatures. The majority of the molecules are cracked into the C5-C16 range. The next subsystem is the purification section. In this section the light ends and heavy ends are separated from the middle distillates, which are known as organic liquid product (OLP). The fatty acids produced during the cracking stage are also removed from the OLP in this subsection.

After purification, the remaining fatty acids (C12-C18 range) are sent through the next subsection, decarboxylation. In this area the carboxylic acids are converted into hydrocarbons and the alkenes are hydrogenated into alkanes through the use of steam. Following decarboxylation, the OLP’s and decarboxylated fatty acids are sent to the final subsystem, trim purification. In this section the OLP’s are purified into transportation fuel products, and the light ends, heavy ends, and fatty acids are purified into saleable byproducts.

All separation and reaction unit operations that are required for the process are shown in the quantitative block flow diagram (BFD). This drawing also shows the mass balance for the individual process areas. The thermal cracking and purification sections are shown on Drawing 00-A-011/sheets 1 & 2. The decarboxylation and trim purification subsections are shown on sheets 3-8.

Drawings 0X-A-012/X show the process flow diagrams for the process. The following detailed process description is based off of the process flow diagrams. Table 53 displays the equipment lettering system, Table 54 shows the equipment number codes, and Table 55 presents an example equipment number scheme. These tables explain how the equipment in Tables 56-64 were coded. Table I.2 in Appendix I shows examples of all the equipment used in the drawings. Table 65 shows the drawing number codes, and Table 66 displays an example of how the drawings are named.

IV.A.1. Thermal Cracking Section (Drawings 01-A-012/X)

TG oil is assumed to enter the process from storage at 1000 kg/min, a temperature of 20 °C, and a pressure of 140 kPa (stream 1). In order to heat the incoming oil to the desired temperature (410 °C) it is first sent through the post cracking cooler (E-701 A/B). This heat exchanger uses the excess heat of the products coming out of the TTCR (R-201) in stream 11 to preheat the feed. E-701 A/B heats the oil to 310 °C, and then it is pressurized to the reaction pressure of 1930 kPa by L-201 A/B. Following the pre-cracking pump, the oil is heated to the desired temperature of 410 °C in E-802 A/B. The soybean oil then enters the TTCR (R-201) in Stream 8 on Drawing 01-A-012/2 at 410 °C and 1900 kPa.

The Turbulent Tubular Cracking Reactor is used to noncatalytically crack the TG oil into transportation fuel intermediates. The majority of these molecules are in the C5-C16 carbon number range. This reactor was designed to be 6.1 m in diameter and 12.2 m in length with 10300 tubes. It operates at a temperature of 430 °C and 1800 kPa, and has a residence time of 1.17 hr. The soybean oil and crackate flow through the tube side of the reactor, and the superheated steam (435 °C and 6000 kPa) that heats the reactor flows through the shell side. The products leaving the reactor are used to heat the incoming soybean oil in E-701 A/B, and are then sent to the purification section of the plant in Stream 12 at 1000 kg/min, 230 °C, and 1760 kPa.

IV.A.2. Purification Section (Drawings 02-A-012/X)

Following the thermal cracking section of the plant is the purification section. In this section the middle distillates are separated from the light and heavy ends, and the fatty acids are removed from the middle distillates. First, the cooled TTCR products

(Stream 12) are sent to the acetic acid separator 1 (D-604). In this flash drum the majority of the C1-C8 carbon length molecules (Stream 17) are flashed off of the remaining C7-C50 molecules by flashing the incoming stream to 1380 kPa. In addition to the removal of the lighter compounds, some of the acetic acid that is produced in the TTCR separates out from the organic phase. This aqueous acetic acid, with small amounts of propionic acid, are removed from the organic liquid product in Stream 15. The organic liquid is then flashed again in D-601 at 690 kPa. In this flash drum the remaining lighter molecules are removed in Stream 19, leaving the liquid products in Stream 18. Streams 17 and 19 are then sent to D-605 on Drawing 02-A-012/3, and Stream 18 is sent to E-702 A/B on Drawing 02-A-012/2.

Stream 18 is first cooled to 150 °C in E-702 A/B, and is then flashed a third time in D-602. This flash drum operates at 140 kPa. The liquid products are then sent to the fatty acid extractor on Drawing 02-A-012/4 in Stream 23. The gas products from D-602 are first compressed by G-201 A/B to 420 kPa, and are then sent to D-605 on Drawing 02-A-012/3 in Stream 25.

Streams 17 and 19 from sheet 1 are sent into acetic flash drum 2 on Drawing 02-A-012/3. Stream 25 from G-201 on sheet 2 is also sent into this flash drum. D-605 removes the light ends in the C1-C6 carbon range in the gas product in Stream 56. The remaining C6-C8 organic liquid is removed in Stream 57. D-605 also has a small amount of acetic and propionic acid, which separate out from the organic liquid phase into an aqueous phase. This product (Stream 58) is combined with Stream 15 in D-821 to form Stream 72. Stream 72 is then sent to combine with the bottom products out of D-703 on Drawing 07-A-012/1. From D-605, stream 56 is sent to D-603 on Drawing 05-A-012/1 for light end purification. Stream 57, the C6-C8 organic liquid, is sent to combine with the tops from the atmospheric distillation column (D-701) as shown on Drawing 02-A-012/5.

Stream 23, the organic liquids, from D-602 shown on Drawing 02-A-012/2 is combined with 770 kg/min of 25 wt% trimethylamine (TMA) solvent in the fatty acid extractor (D-901 A/B). D-901 A/B is 6.6 m tall and 2.2 m in diameter, and operates at 38 °C and 140 kPa. The solvent and the middle distillates are combined in the extractor for a residence time of 15 min. The TMA removes the fatty acids within the organic liquids generated earlier in the process. The TMA/fatty acid and organic mixture then exits the extractor in Stream 4, and are sent to D-902 (fatty acid separator). D-902 separates the aqueous TMA/fatty acid stream from the organic stream. The fatty acid/TMA mixture is then sent to D-703 (water removal column) in Stream 13 at a flow rate of 910 kg/min at 38 °C and 140 kPa. The organic stream, Stream 88 from D-7013 is pressurized to 170 kPa by L-203 A/B, and heated to 135 °C in E-802 A/B. The organic stream is then sent to the atmospheric distillation column (D-701) shown on Drawing 02-A-012/5 as Stream 207.

The atmospheric distillation column (D-701), shown on Drawing 02-A-012/5, separates the naphtha/kerosene range fuel intermediates from the heavier diesel fuel range intermediates. D-701 splits the incoming Stream 207 at the C12-C13 carbon range. The distillate products (C7-C12) leave the top of the column at 210 °C and 131 kPa. They are first condensed at 55 °C in E-601 A/B and pressurized to 210 kPa by L-246 A/B prior to combining with Stream 57. The combined streams, Stream 210, are then sent to the hexane splitter column (D-715) on Drawing 04-A-012/1. The bottoms from D-701 exit the column at 270 °C and 140 kPa. They are then heated to 322 °C in E-901 A/B and are then sent to vacuum distillation column D-702 as Stream 32 at 500 kg/min. D-701 is 8.2 m tall, 2.41 m in diameter, and has 7 trays. The feed enters the column at tray 5, and the column operates with a reflux ratio of 0.1.

Stream 32 enters the vacuum column (D-702) on Drawing 02-A-012/6 at tray 10. D-702 operates at 30 kPa, and has a height of 21.8 m, diameter of 4.4 m, and 20 trays. D-702 separates the diesel range fuel intermediates from the heavy end byproducts. This separation occurs at the C30 range, with the diesel fuel intermediates leaving in the distillate (C12-C30), and the heavy ends leaving the bottom (C30-C50). The distillate leaves D-702 at 260 °C and 28 kPa. It is then cooled to 220 °C in E-602 A/B. The reflux is then sent back to the column at a reflux ratio of 0.6, and the distillates head to trim purification in D-715 at 220 °C, 140 kPa and 250 kg/min in Stream 49. The bottoms exit D-702 at 340 °C and 34 kPa. They are then heated to 350 °C in E-902 A/B, and shipped to storage as the Vacuum Bottoms (Stream 40) byproduct, which is generated at a rate of 250 kg/min.

IV.A.3. Trim Purification Section (Drawings 04-A-012/X)

Streams 201 and 41 from Drawings 02-A-012/5 and 05-A-012/1, respectively, enter the hexane splitter column (D-715), shown on Drawing 04-A-012/1. D-715 separates the lighter components (compounds C1-C4) from the naphtha-diesel range (compounds C5-C12). D-715 is 7.9 m tall, with a 0.9 m diameter, 8 trays, and the first feed enters the column on tray 4, and the second feed enters on tray 3. The distillate products exit the column at 47 °C and 97 kPa. They are then partially condensed at 35 °C by E-603 A/B. The resulting gaseous distillate product leaves the reflux drum (D-815 A/B) in stream 94 at 17 kg/min, and is sent to light end purification shown on Drawing

05-A-012/1. The reflux is pumped back to the column at a reflux ratio of 1.8 through L-212 A/B. The bottoms, Stream 148, exit D-715 at 115 °C and 110 kPa. They are then heated to 141 °C by E-904 A/B prior to being pumped to D-716 on Drawing 04-A-012/3 by L-211 in Stream 150 at 200 kg/min.

Stream 150 enters the naphtha-jet cut column (D-716) shown on Drawing 04-A-012/3. D-716 separates the naphtha product (C5-C9) from the jet fuel product (C9-C12). D-716 has a height of 27.7 m, diameter of 1.6 m, 30 trays, and a feed tray of 7. The distillate exits D-716 at 112 °C and 124 kPa. It is then condensed at 88 °C by E-604 A/B, and pressurized to 150 kPa by L-213 A/B. The distillate, Stream 156, is sent to E-1001 A/B shown on Drawing 04-A-012/6 at a rate of 45 kg/min, and the reflux is sent back to the column in Stream 157 at a reflux ratio of 1.25. The bottoms exit D-716 at 180 °C and 160 kPa. They are heated to 200 °C by E-905 A/B. The bottoms in Stream 162 are sent to E-1005 A/B shown on Drawing 04-A-012/6 at a rate of 150 kg/min.

Stream 49 from L-247 A/B shown on Drawing 02-A-012/6 is pressurized to 210 kPa by L-214 A/B. It is then heated to 210 °C by E-714 A/B. After heating, Stream 41 from D-607 shown on Drawing 03-A-012/2 is pressurized to 170 kPa by L-259 A/B. Stream 49 and 41 are then combined to form Stream 62, which is sent to D-717 at 200 °C and 170 kPa at a rate of 300 kg/min.

Stream 62 enters D-717 on tray 13. D-717 splits the jet fuel product (C8-C15) from the diesel fuel no. 2 product (C16-C30). D-717 is 24.8 m tall, 3.0 m in diameter, and has 25 trays. The distillate exits D-717 at 243 °C and 104 kPa. It is then condensed at 230 °C by E-605 A/B, and pressurized to 124 kPa by L-215 A/B. The distillate products leave L-215 A/B in Stream 172 at a rate 64 kg/min and is sent to E-1002 A/B to be cooled further. The reflux is pumped back through the column in Stream 173 at a reflux ratio of 4.6. The bottoms exit the column at 290 °C and 117 kPa, and are heated to 300 °C by E-903 A/B. The bottoms are then pumped to 170 kPa in Stream 178 by L-216 A/B at a flow rate of 240 kg/min. Stream 178 then enters the diesel fuel oil cut column (D-718) shown on Drawing 04-A-012/5.

D-718 (Drawing 04-A-012/5) splits the diesel fuel range intermediates from the bottom fuel oil intermediates. This column is 47.9 m tall, 4.3 m in diameter, has 50 trays, and a feed to tray 23. The diesel fuel range molecules (C16-C21) exit the top of the column at 340 °C and 140 kPa. They are then cooled to 330 °C by E-606 A/B prior to being pressurized to 150 kPa by L-217 A/B. The reflux is then sent back to the column at a reflux ratio of 0.5, and the diesel fuel intermediates are sent to E-1003 A/B shown on Drawing 04-A-012/7 in Stream 184 at a flow rate of 240 kg/min. The fuel oil intermediates flow out the bottom of the column at 390 °C and 170 kPa. They are then heated in the reboiler (E-906 A/B) to 395 °C. The fuel oil intermediates are sent to E-1005 A/B shown on Drawing 04-A-012/7 in Stream 189 at a flow rate of 2 kg/min.

Stream 156, from D-716 shown on Drawing 04-A-012/3, is combined with Stream 163 from E-908 A/B shown on Drawing 05-A-012/4 to form the naphtha stream product, Stream 191, in D-822 as shown on Drawing 04-A-012/6. Stream 191 is cooled to 32 °C by E-1001 A/B, as shown on Drawing 04-A-012/6, and pressurized to 170 kPa in Stream 193 at a flow rate of 86 kg/min and sent to storage.

Stream 162 from E-905 A/B on Drawing 04-A-012/3 and Stream 172 from L-215 A/B on Drawing 04-A-012/4 combine to form the jet fuel product stream, Stream 192, on

Drawing 04-A-012/6. This stream is cooled to 32 °C by E-1002 A/B, pressurized to 170 kPa by L-242 A/B, Stream 192, and sent to storage at a rate of 210 kg/min.

Stream 184 is routed from L-217 A/B, as shown on Drawing 04-A-012/5, to E-1003 A/B and cooled to 60 °C. This stream, Stream 201, is then further cooled to 32 °C by E-1004 A/B and sent to storage as the diesel fuel no. 2 product at a rate of 240 kg/min.

Stream 189 from E-906 A/B on Drawing 04-A-012/5 is cooled to 60 °C by E-1005 A/B on Drawing 04-A-012/7. The stream exiting the fuel oil cooler (E-1005 A/B), Stream 204, is fuel oil no. 5, and is sent to the boiler to serve as fuel at a rate of 2 kg/min.

IV.A.4. Light End Processing Section (Drawing 05-A-012/X)

Stream 66 from D-606 on Drawing 03-A-012/2 is cooled to 38 °C in E-703 A/B shown on Drawing 05-A-012/1 prior to entering flash 3 (D-603). Streams 67 from G-202 A/B and 56 from D-605, shown on Drawings 03-A-012/2 and 02-A-012/3, respectively, combine together and also enters D-603. D-603 separates the naphtha range fuel intermediates (C5-C7) from the light ends (C1-C4). The naphtha range intermediates exit D-603 out the bottom at 21 °C and 103 kPa in Stream 41. Stream 41 is then pressurized to 170 kPa by L-258 A/B, and sent to D-715 shown on Drawing 04-A-012/1 at 14 kg/min. Stream 71 exits the top of D-603 at 21 °C and 103 kPa, and combines with Stream 94 from D-815 A/B on Drawing 04-A-012/1. The two streams combine to form Stream 73, which is at 21 °C and 103 kPa. Stream 73 flows to G-203, shown on Drawing 05-A-012/2, at 180 kg/min.

Stream 73 enters the light end compressor (G-203) shown on Drawing 05-A-012/2. G-203 is a three stage compressor. The stream is pressurized to 415 kPa and heated to 143 °C in the first stage. It is then cooled by the interstage cooler 1 (E-705 A/B) to 35 °C before entering the second stage of the compressor. The stream is then pressurized to 1520 kPa in stage two, and is also heated to 188 °C. It then flows through the interstage cooler 2 (E-706 A/B), and is cooled to 35 °C before entering the third stage. Stream 105 then exits G-203 at 166 °C and 3310 kPa, and proceeds to the syngas column (D-719), shown on Drawing 05-A-012/3, at 180 kg/min.

Stream 105 is cooled to 32 °C by E-704 A/B, as on shown Drawing 05-A-012/3. It then enters the syngas column (D-719) on tray 15. D-719 is 37.1 m tall and 0.2 m in diameter with 40 trays. The syngas column removes the syngas (C1-C3) from the butane and naphtha fuel range products. The syngas exits the top of the column at 8 °C and 3240 kPa, and is partially condensed at -9 °C by low temperature refrigerant in E-607 A/B. The syngas product is then sent to the boiler to be used as boiler feed in Stream 110 at 120 kg/min, and the reflux is sent back into the column at a reflux ratio of 0.3. The bottom product exits D-719 at 170 °C and 3260 kPa, and is heated to 180 °C by E-907 A/B. The bottom product is sent to the debutanizer column feed cooler E-707 as Stream 115 at a rate of 59 kg/min.

Stream 115 is cooled to 120 °C by E-707 A/B (Drawing 05-A-012/4). This stream then enters D-720 (debutanizer column) on tray 8. D-720 is 11.2 m tall and 0.9 m in diameter, and contains 12 trays. D-720 removes the butane product from the heavier naphtha range products. The butane product exits the top of D-720 at 69 °C and 830 kPa. It is then partially condensed at 67 °C by E-608 A/B. The butane product is then sent to storage in Stream 123 at 19 kg/min. The reflux is sent back to the column at a reflux ratio of 5.5. The bottoms leave D-720 at 120 °C and 834 kPa, and are heated to 130 °C by E-

908 A/B. The bottoms product, Stream 163 (39 kg/min), is then combined with Stream 156 on Drawing 04-A-012/6 to produce the Naphtha product which is routed to storage.

IV.A.5. Fatty Acid Recovery Section (Drawing 07-A-012/X)

Stream 13 from D-902 on Drawing 02-A-012/4 enters the water removal column (D-703) shown on Drawing 07-A-012/1. D-703 removes the majority of the water and all of the TMA from the recovered fatty acids. D-703 has a height of 18.8 m, diameter of 2.2 m, 19 trays, and a feed tray of 12. The distillate exits the top of D-703 at 92 °C and 48 kPa. It is then condensed to 67 °C by E-609 A/B, and pressurized to 76 kPa by L-218 A/B. The distillate in Stream 78 is sent to combine with the distillate from D-705 on Drawing 07-A-012/3 in Stream 78 at a rate of 740 kg/min, and the reflux is sent back to the column at a ratio of 0.8 in Stream 79. The bottoms exit D-703 at 94 °C and 76 kPa. They are then heated to 103 °C by E-909 A/B prior to being pressurized to 140 kPa by L-219 A/B. The bottoms product, Stream 83, combines with Stream 72 from D-821 to form Stream 211, which is sent to D-704 on Drawing 07-A-012/2.

Stream 211 enters the C2-C4 split column (D-704) on tray 16. The C2-C4 split column is 19 m tall, 1.6 m in diameter, and has 20 trays. D-704 separates the remaining water and acetic acid from the C3 and heavier fatty acids. The distillate exits D-704 in Stream 212 at 53 °C and 14 kPa. It is then condensed at 51 °C by E-610 A/B. The distillate is then pressurized to 110 kPa by L-249 A/B and sent to D-705 on Drawing 07-A-012/3 as Stream 214 at 36 kg/min. The reflux is pressurized to 28 kPa by L-223 A/B and sent back to D-704 at a reflux ratio of 2.4. The bottoms exit D-704 at 133 °C and 21 kPa, and are heated to 173 °C by E-910 A/B (C2-C4 split reboiler). They are then pressurized to 140 kPa by L-222 A/B before being cooled to 160 °C in E-708 A/B. The bottoms are then sent to D-706 on Drawing 07-A-012/4 as Stream 221 at 130 kg/min.

Stream 214 from D-704 enters the acetic acid column (D-705) as shown on Drawing 07-A-012/3. D-705 removes the acetic acid from the remaining water. D-705 has a height of 20.7 m, diameter of 1.5 m, 22 trays, and a feed on tray 12. The distillate exits D-705 at 117 °C and 103 kPa. It is then condensed at 115 °C by E-611 A/B prior to being pressurized to 140 kPa by L-221 A/B. The distillate, Stream 226, is combined with Stream 78 from L-220 A/B to form Stream 233. Stream 233 is the TMA rich solvent and is sent back to D-901 as recycle. The reflux is sent back to D-705 in Stream 227 at a reflux ratio of 3.5. The bottoms exit D-705 at 128 °C and 120 kPa, and are heated to 131 °C by E-911 A/B. The bottoms product is sent to storage as Stream 231 at a flow rate of 5 kg/min as the Acetic Acid product stream.

Stream 221 from E-708 A/B on Drawing 07-A-012/2 enters D-706 (C6-C7 split column), as shown on Drawing 07-A-012/4, on tray 15. D-706 separates the C3-C6 fatty acids from the heavier acids (C7-C18). D-706 is 31.5 m tall, 1.1 m in diameter, and has 35 trays. The distillate leaves the top of D-706 at 194 °C and 103 kPa and is condensed at 185 °C by E-612 A/B. The tops are then pressurized to 140 kPa by L-224 A/B, and the distillate product is sent to D-707 on Drawing 07-A-012/5 as Stream 240 at a rate of 10 kg/min. The reflux is sent back to the column in Stream 241 at a ratio of 4.8. The bottoms leave D-706 at 245 °C and 124 kPa in Stream 244. They are then heated to 260 °C by the C6-C7 reboiler (E-912 A/B) and pressurized to 140 kPa by L-225 A/B. The bottom product (Stream 247) is then cooled to 200 °C by E-710 A/B, and sent to D-710 on Drawing 07-A-012/8.

Stream 240 from D-706 on Drawing 07-A-012/4 is first cooled to 93 °C prior to entering D-707, the C4-C5 split column. D-707 separates the C3-C4 fatty acids from the C5-C6 fatty acids. D-707 is 28.3 m tall, has a 0.4 m diameter, 32 trays, and a feed on tray 12. The bottoms exit D-707 at 167 °C and 62 kPa. They are then heated to 168 °C by E-913 A/B, and are pressurized to 140 kPa by L-227 A/B. They are then sent to D-709 on Drawing 07-A-012/7 in Stream 263 at a rate of 9 kg/min. The distillate leaves the top of D-707 at 130 °C and 41 kPa and are condensed at 125 °C by E-613 A/B. The distillate product is then pressurized to 140 kPa by L-250 A/B and sent to D-708 on Drawing 07-A-012/6 in Stream 254. The reflux is pumped back to D-707 by L-226 A/B in Stream 255 at a reflux ratio of 4.9.

Stream 254 from D-707 on Drawing 07-A-012/5 is first heated to 135 °C by E-803 A/B on Drawing 07-A-012/6 prior to entering D-708. D-708 separates the propionic acid byproduct from the butyric acid byproduct. D-708 is 24.7 m tall, 0.3 m in diameter, has 28 trays, and a feed on tray 15. The distillate exits the top of D-708 at 130 °C and 69 kPa. It is then condensed at 127 °C by E-614 A/B and pressurized to 170 kPa by L-251 A/B. The propionic byproduct is then sent to storage as Stream 302 at a flow rate of 1 kg/min. The reflux is pumped back to D-708 by L-228 A/B in Stream 303 at a reflux ratio of 9.3. The bottoms exit D-708 at 150 °C and 83 kPa, and are heated to 152 °C by E-914 A/B. The butyric acid byproduct is then pressurized to 170 kPa by L-229 A/B, and sent to storage as Stream 311 at a flow rate of 1 kg/min.

Stream 263 from L-227 A/B on Drawing 07-A-012/5 enters D-709 on tray 15, as shown on Drawing 07-A-012/7. D-709 separates the valeric acid byproduct from the caproic acid byproduct. D-709 is 26.7 m tall, 0.6 m in diameter, has 30 trays, and a feed on tray 15. The distillate leaves the top of D-709 at 184 °C and 97 kPa. It is then condensed at 183 °C by E-615 A/B, and the valeric acid byproduct is pressurized to 170 kPa by L-252 A/B and sent to storage as Stream 316 at 3 kg/min. The reflux is pressurized to 110 kPa by L-231 A/B and sent back to D-709 in Stream 317 at a reflux rate of 8.2. The bottoms leave D-709 at 200 °C and 110 kPa and are heated to 204 °C by E-915 A/B. The caproic acid byproduct is then pressurized to 170 kPa by L-230 A/B as Stream 322, and is then sent to storage at 5 kg/min.

Stream 247 from the C6-C7 split column (D-706) on Drawing 07-A-012/4 enters the C8-C9 split column (D-710) on tray 15, shown on Drawing 07-A-012/8. D-710 separates the C7-C8 fatty acids from the C9-C18 fatty acids. D-710 is 24.7 m tall, 2.1 m in diameter, and has 26 trays. The distillate exits the top of D-710 at 200 °C and 41 kPa, and is condensed at 198 °C by E-616 A/B. The distillate product is then pressurized to 103 kPa by L-253 A/B prior to being sent to D-711 in Stream 327 at 26 kg/min. The reflux is pressurized to 55 kPa by L-233, and recycled back to D-710 in stream 328 at a reflux ratio of 6.3. The bottoms exit D-710 at 240 °C and 62 kPa. They are then heated to 258 °C by E-916 A/B. The bottoms product then flows to L-232 A/B, and is pressurized to 140 kPa before entering E-711 A/B. E-711 A/B cools Stream 335 to 246 °C, and Stream 335 is then sent to D-712 at a flow rate of 91 kg/min.

Stream 327 from L-253 A/B on Drawing 07-A-012/8 enters D-711 (C7-C8 product column) on tray 15, as shown on Drawing 07-A-012/9. D-711 is 25.7 m tall, 1.3 m in diameter, has 28 trays, and separates the C7 fatty acid product from the C8 fatty acid product. The bottoms exit D-711 at 207 °C and 62 kPa. They are then heated to 208 °C by E-917 A/B before being pressurized to 170 kPa by L-234 A/B. The octanoic acid byproduct is then sent to storage as Stream 348 at a flow rate of 11 kg/min. The distillate exits the top of D-711 at 193 °C and 41 kPa. They are then condensed at 192 °C by E-617 A/B. The reflux is pumped back to D-711 by L-233 A/B in Stream 343 at a reflux ratio of 4.8, and the heptanoic acid byproduct is pressurized to 170 kPa by L-254 A/B before being sent to storage as Stream 342 at a flow rate of 15 kg/min.

Stream 335 enters D-712 on Drawing 07-A-012/10. The C10-C11 split column (D-712) is 30.3 m tall, 2.4 m in diameter, has 32 trays, and a feed on tray 19. D-712 separates the C9 and C10 fatty acids from C11-C18 fatty acids. The distillate leaves the top of D-712 at 218 °C and 28 kPa. It is then condensed at 216 °C by E-618 A/B, and the reflux is pressurized to 41 kPa by L-237 A/B and pumped back to D-712 at a reflux ratio of 6.3. The distillate product is pressurized to 103 kPa by L-255 A/B, and is sent to D-713 on Drawing 07-A-012/11 in Stream 353 at a flow rate of 24 kg/min. The bottoms exit the bottom of D-712 at 262 °C and 34 kPa. They are then heated to 278 °C by E-918 A/B. The bottoms products are then pressurized to 140 kPa by L-236 A/B, and cooled to 226 °C by E-712 A/B before being sent to D-714 on Drawing 07-A-012/12 in Stream 361 at a flow rate of 68 kg/min.

Stream 353 enters D-713, shown on Drawing 07-A-012/11, on tray 17. D-713 (C9-C10 product column) separates the C9 fatty acid byproduct from the C10 fatty acid byproduct. This column in 29.4 m tall, 1.5 m in diameter, and has 32 trays. The distillate exits D-713 at 211 °C and 28 kPa. It is then condensed at 210 °C by E-619 A/B, and the nananoic acid byproduct is pressurized to 170 kPa by L-256 A/B. The C9 fatty acid is then sent to storage as Stream 368 at a flow rate of 14 kg/min. The reflux is pressurized to 41 kPa by L-244 A/B, and sent back to D-713 at a reflux ratio of 5.9. The bottoms exit

D-713 at 223 °C and 34 kPa. They are then heated to 224 °C, and the decanoic acid byproduct is pressurized to 170 kPa by L-239 A/B before being sent to storage as Stream 374 at a flow rate of 11 kg/min.

D-714 (C11 product column) on Drawing 07-A-012/12 separates the C11 fatty acid byproduct from the C12-C18 fatty acids. D-714 is 27.8 m tall, 1.7 m in diameter, and has 30 trays. Stream 361, from E-712 A/B, enters D-714 on tray 17, and the distillate leaves the top at 216 °C and 14 kPa. The tops are then condensed at 214 °C by E-620 A/B, and the undecanoic acid byproduct is pressurized to 170 kPa by L-257 A/B. The undecanoic acid is then sent to storage as Stream 380 at a flow rate of 5 kg/min. The reflux is pressurized to 21 kPa by L-240 A/B and sent back to D-714 at a reflux ratio of 11.4. The bottoms leave D-714 at 254 °C and 21 kPa. They are heated to 263 °C by E-919 A/B, and pressurized to 3170 kPa by L-241 A/B. The bottoms products (Stream 386) are then heated to 320 °C by E-804 A/B. Stream 386 contains C12-C18 fatty acids that are recovered as separate byproducts. Stream 386 is sent to R-202 A/B shown on Drawing 03-A-012/1. It should be noted that higher carbon number fatty acids could be recovered with additional columns if this was desired.

IV.A.6. Decarboxylation Section (Drawing 03-A-012/X)

Stream 386 from E-804 A/B on Drawing 07-A-012/12 is sent through the fatty acid decarboxylation reaction (R-202 A/B) on Drawing 03-A-012/1. Stream 386 enters R-202 A/B at 320 °C and 3140 kPa. Process steam at 315 °C and 2210 kPa also enters the reactor at a flow rate of 2 kg/min to provide a hydrogen donor source. The steam and feed stream react in R-202 A/B to convert the remaining fatty acids alkanes. This results in a significant amount of CO2 produced, as well as smaller fuel intermediate molecules (C1-

C6). R-202 A/B is 1.8 m in diameter and 11.2 m in length with a catalyst volume of 62 m^3. The products exit the reactor in Stream 393 at 320 °C and 2210 kPa at a flow rate of 66 kg/min. Stream 393 is then cooled to 176 °C by E-713 A/B prior to being sent to Flash 4 (D-606) on Drawing 03-A-012/2 as Stream 394.

Stream 394 from E-713 A/B enters D-606 on Drawing 03-A-012/2. D-606 flashes the incoming feed to 1720 kPa, and separates the majority of the light components formed during decarboxylation (C1-C7) from the fuel intermediates (C5-C18). The gaseous products from D-606 exit as Stream 66 at 174 °C and 1720 kPa and are routed to the light end purification section, as shown on Drawing 05-A-012/1. The liquid products exit D-606 at 174 °C and 1720 kPa in Stream 397, and are further flashed to 103 kPa in D-607. Flash drum 5 (D-607) removes any remaining light ends in the fuel intermediates. The light ends exit D-607 in Stream 398 at 171 °C and a flow rate of 1 kg/min, and are pressurized to 243 kPa by G-202 A/B before being sent to the light end purification section, as shown on Drawing 05-A-012/1. The liquid products exit D-607 at 171 °C at a flow rate of 50 kg/min, and are sent to the trim purification section as on Drawing 04-A-012/2.

IV.B. Economic Assessment

IV.B.1. Broad Cost Estimate

The capital cost summary for the fatty acid recovery design is shown in Table 67. This table shows the total capital investment needed to complete the project, and was developed as described in Chapter II. The FCI was found to be $100 million, and the TCI was estimated to be $120 million ± 40%.

IV.B.2. Raw Material and Manufacturing Cost Estimate

The raw material cost is based on purchasing crude soybean oil for \$0.60/kg [20]. The total raw material cost is \$300 million per year.

The total manufacturing cost for the fatty acid recovery design is \$18 million per year, and \$20 million per year on years the entire catalyst bed needs to be replaced. The manufacturing cost includes chemicals and catalysts costs, operating labor costs, maintenance costs, and utility costs. Table 68 shows the overall yearly operating expense summary for the fatty acid recovery design. The plant has an operating factor of 95%. Intermediate results can be found in Appendix C, and communication records can be found in Appendix G.

The catalyst used for the decarboxylation reactors in the fatty acid recovery design was a Ni catalyst. The initial charge for the catalyst (shown on the broad cost estimate) covers the total amount of catalyst needed (62 m^3) for a price of \$2.2 million. This amount is charged every four years in order to recharge the catalyst. It was assumed there was a 4% yearly depletion of the catalyst that needed to be replaced for the in between years. This results in a cost of \$86,000 for those years. A quote from Johnson Matthey Catalysts was used for pricing (\$28/m^3).

The chemical needed for the extraction of the fatty acids from the crackate is 25 wt% trimethylamine (TMA). The initial charge for the chemical (shown on the broad cost estimate) covers the total amount of solvent needed for the extraction process (14,000 kg) for a price of \$500,000. It was assumed there was a 17% yearly depletion that needed to be replaced. This resulted in a yearly cost of \$86,000. A quote from Penta International Corporation was used for pricing (\$7.50/kg).

Taking into account both the chemicals and catalysts, a total charge of $170,000 per year for years the catalyst is not recharged. Every four years the catalyst is recharged, which results in a charge of $2.2 million.

The fatty acid recovery design consists of an equivalent of 41 major unit operations, which equates to 55 new operators to cover continuous operation, as described in Chapter II. An average operator salary of $62,800 was used, and taking into account an additional 15% for supervision, the yearly operating expense equates out to $4,000,000 per year [53]. The maintenance costs were found to be $6.1 million per year.

The utility costs is $7,600,000 per year. This value includes the boiler feed water, cooling water, electricity, refrigeration, process water, and natural gas needed to run the plant. The prices for all the utilities, except the electricity and natural gas, were priced based off of Turton heuristics. The natural gas and electricity values were found from typical ND and MN values [57].

IV.B.3. Revenues

Revenue for the fatty acid recovery design comes from the sales of jet fuel, diesel fuel no. 2, petroleum naphtha, butane, vacuum bottoms, and C2-C11 fatty acids. Shipping costs were not considered when calculating the amount of revenues generated.

The transportation fuels, jet fuel, diesel fuel no. 2, and petroleum naphtha, produce a revenue of $160 million/year. This value was based on the production of 79,000 liquid m^3/year of petroleum naphtha that can be sold for $0.36/L, jet fuel at a rate of $190,000 liquid m^3/year which is sold for $0.37/L, and diesel fuel no. 2 produced at 260,000 liquid m^3/year and sold at $0.37/L. The remaining by products produce a revenue of $260 million/year. The total annual revenue for the fatty acid recovery design is $420 million/year.

IV.B.4. Overall Profitability

The cash flow sheet for the fatty acid recovery design is shown in Table 69. The process has a NPV@12% of $340 million ±40%. The project produces a gross income of $100 million per year, and has a DCFROR value of 45%. The positive NPV@12% value and a DCFROR value greater than 12% show that the investment is profitable over the project lifecycle.

IV.C. Break Even Point

With the current design and prices of products and raw materials, the process recovers the initial investment within three years. In order for the process to break even over the 20 year lifecycle, the price of soybean oil would have to rise to a price of $0.76/kg, which last happened in October of 2014, or the price of the products would have to lower significantly. The cash flow sheet based on this raw material price is shown in Table 70.

In order to make the process more economically feasible, processing of the heavy end will help to produce an additional profitable by product and produce a larger quantity of transportation fuels. This analysis was performed in Chapter V. Also, an analysis with crop oil integration was performed in Chapter VI, and a hazard analysis was performed on the margin between the transportation fuel products and raw material cost in Chapter VII.

Table 42. Soybean oil composition.

Component	Weight %
Linolenic Acid	12%
Linoleic Acid	51%
Oleic Acid	23%
Stearic Acid	4%
Palmitic Acid	10%

Table 43. Raw materials list for fatty acid recovery design.

Raw Material	Amount
Soybean Oil	600,000 m^3/year

Table 44. Transportation fuel products from fatty acid recovery design.

Product	Amount (liquid m^3/year)
Petroleum Naphtha	79,000
Jet Fuel	190,000
Diesel Fuel No. 2	260,000

Table 45. Petroleum naphtha product properties from fatty acid recovery design.

Specification	Measurement
Density at 15 °C	700 kg/m3
Total paraffins volume %	62%
Olefins volume %	1%
Aromatics volume %	1.3%
Initial boiling point	53 °C
Temperature at 5% recovered	55 °C
Temperature at 10% recovered	62 °C
Temperature at 20% recovered	67 °C
Temperature at 30% recovered	79 °C
Temperature at 40% recovered	82 °C
Temperature at 50% recovered	84 °C
Temperature at 60% recovered	91 °C
Temperature at 70% recovered	94 °C
Temperature at 80% recovered	98 °C
Temperature at 90% recovered	112 °C
Final boiling point	127 °C
Reid vapor pressure at 37.8 °C	110 kPa

Table 46. Jet fuel product properties from fatty acid recovery design.

Specification	Measurement
Aromatics volume %	12.6 %
Temperature at 10% recovered	161 °C
Temperature at 50% recovered	203 °C
Temperature at 90% recovered	253 °C
Final boiling point	267 °C
Flash point	43 °C
Density at 15 °C	783 kg/m3
Freezing point	-46.7 °C
Viscosity at -20 °C,	3.0 mm2/s
Net heat of combustion	43.07 MJ/kg
Smoke point	26.58 mm
Cetane number	54.9

Table 47. Diesel fuel no. 2 product properties from fatty acid recovery design.

Specification	Measurement
Flash point	118 °C
Water volume %	0%
Temperature at 90% recovered	336 °C
Kinematic viscosity at 40 °C	3.2 mm2/s
Cetane number	79.3
Aromaticity volume %	12.9 %
Cloud point	4.0 °C

Table 48. Byproduct production in fatty acid recovery design.

Product	Amount (liquid m^3/year)
Butane	22,000
Acetic Acid	3,200
Propionic Acid	370
Butyric Acid	750
Valeric Acid	2,300
Caproic Acid	4,500
Heptanoic Acid	12,000
Octanoic Acid	8,700
Nananoic Acid	9,800
Decanoic Acid	9,300
Undecanoic Acid	3,700
Vacuum Bottoms	230,000

Table 49. Butane product properties from fatty acid recovery design.

Specification	Measurement
Vapor pressure at 37.8 °C	397 kPa
Temperature at 95% recovered	2.2 °C
Pentane and heavier volume %	2.0 %
Relative density at 15.6/15.6°C	0.59
Free water content	0

Table 50. Boiler fuel products produced in fatty acid recovery design.

Fuel	Amount
Syngas	1,300,000 Nm^3 gas/year
Fuel Oil No. 5	2,500 liquid m^3/year

Table 51. Initial charge of chemicals and catalysts required for fatty acid recovery design.

Chemical/Catalyst	**Amount**
Ni/SiO_2 Catalyst	62 m^3
Trimethylamine	14,000 kg

Table 52. Utility requirements for fatty acid recovery design.

Utility	**Amount**
Boiler Feed Water	6,900,000,000 kg/year
Cooling Water	32,800,000 m^3/year
Electricity	15,100,000 kW
Refrigeration (Low Temp)	180,000,000 kg/year
Process Steam	940,000 kg/year
Natural Gas	11,000,000 N m^3/year

Table 53. Equipment lettering system [47].

Letter	Definition
D	Process (Pressure) Vessels
E	Heat Exchangers
F	Storage Vessels
G	Gas Movers
L	Pumps
P	Package Units
Q	Furnaces
R	Reactors

Table 54. Equipment number codes and corresponding definitions for fatty acid recovery design.

Code	Definition
D-600 Series	Flash Drums
D-700 Series	Distillation Columns
D-800 Series	Reflux Drums
D-900 Series	Extraction Equipment
E-600 Series	Column Condensers
E-700 Series	Cooler Heat Exchangers
E-800 Series	Heater Heat Exchangers
E-900 Series	Column Reboilers
E-1000 Series	Product Coolers
D-1000 Series	Knockout Drums
G-200 Series	Compressors
L-200 Series	Pumps
P-200 Series	Refrigeration Unit
Q-200 Series	Boilers
R-200 Series	Reactors
1##	Unit Number
A	Equipment 1 for redundant equipment
B	Equipment 2 for redundant equipment

Table 55. Equipment naming system using example number D-601 A.

Code	D	600 Series	601	A
Definition	Pressure Vessels	Flash Drum	First Unit	Equipment piece 1 of 2

Table 56. Flash drum equipment list.

Equipment ID	Equipment Name/Description	Height (m)	Diameter (m)	Orientation	Pressure (kPa) Design Basis	Temperature (°C)	MOC
D-601	Flash 1	5.8	1.4	Vertical	690	210	Stainless Steel Clad
D-602	Flash 2	5.8	1.4	Vertical	140	145	Stainless Steel Clad
D-603	Flash 3	2	1.2	Vertical	103	21	Carbon Steel
D-604	Acetic Acid Separator 1	1.8	0.5	Vertical	1380	215	Stainless Steel Clad
D-605	Acetic Acid Separator 2	3.4	0.8	Vertical	210	54	Stainless Steel Clad
D-606	Flash 4	2.8	0.8	Vertical	1720	174	Carbon Steel
D-607	Flash 5	2.8	0.8	Vertical	103	171	Carbon Steel

Table 57. Distillation column equipment list.

Equipment ID	Equipment Name/Description	Height (m)	Diameter (m)	Trays*	Feed Tray	Pressure (kPa)	Temperature (°C)	MOC: Body	MOC: Trays
D-701	Atmospheric Column	8.2	2.1	7	5	138	322	cs	ss
D-702	Vacuum Column	21.8	4.4	20	10	28	350	cs	ss
D-703	Water Removal Column	18.8	2.2	19	12	69	103	ss clad	ss
D-704	C2-C4 FA Split Column	19	1.6	20	16	14	57	ss clad	ss
D-705	Acetic Acid Column	20.7	1.5	22	12	103	131	ss clad	ss
D-706	C6-C7 FA Split Column	31.5	1.1	35	15	103	264	ss clad	ss
D-707	C4-C5 FA Split Column	28.3	0.4	32	12	41	169	ss clad	ss
D-708	C3-C4 FA Product Column	24.7	0.3	28	15	69	151	ss clad	ss

(continued)

*Based on sieve trays at 80% efficiency

Table 57. Cont.

Equipment ID	Equipment Name/Description	Height (m)	Diameter (m)	Trays*	Feed Tray	Pressure (kPa)	Temperature (°C)	MOC: Body	MOC: Trays
D-709	C5-C6 FA Product Column	26.7	0.6	30	15	97	204	ss clad	Ss
D-710	C8-C9 FA Split Column	24.7	2.1	26	15	41	259	ss clad	ss
D-711	C7-C8 FA Product Column	25.7	1.3	28	15	41	209	ss clad	ss
D-712	C10-C11 FA Split Column	30.3	2.4	32	19	28	262	ss clad	ss
D-713	C9-C10 FA Product Column	29.4	1.5	32	17	28	225	ss clad	ss
D-714	C11 FA Product Column	27.8	1.7	30	17	14	264	ss clad	ss
D-715	Hexane Splitter Column	7.9	0.9	8	3 & 4	103	141	cs	ss
D-716	Naphtha Jet Cut Column	27.7	1.6	30	7	103	196	cs	ss
D-717	Jet Diesel Cut Column	24.8	3	25	13	103	304	cs	ss
D-718	Diesel Fuel Oil Cut Column	47.9	4.3	50	23	103	396	cs	ss
D-719	Syngas Column	37.1	0.2	40	15	3240	183	cs	ss
D-720	Debutanizer Column	11.2	0.9	12	8	827	134	cs	ss

*Based on sieve trays at 80% efficiency

Table 58. Reflux drum equipment list.

Equipment ID	Equipment Name/Description	Volume (m3)	Orientation	Length (m)	Diameter (m)	Temperature (°C)	Pressure (kPa)	Flow Rate (m3/min)	MOC
D-801	Atmospheric Column Reflux Drum	1.5	Horizontal	3	0.8	55	117	0.2	cs
D-802	Vacuum Column Reflux Drum	4.1	Horizontal	4.3	1.1	220	21	0.6	cs
D-803	Water Removal Column Reflux Drum	8.5	Horizontal	5.5	1.4	67	34	1.4	ss clad
D-804	C2-C4 FA Split Column Reflux Drum	0.7	Horizontal	2.4	0.6	51	7	0.2	ss clad
D-805	Acetic Acid Column Reflux Drum	1.5	Horizontal	3	0.8	115	90	0.2	ss clad
D-806	C6-C7 FA Split Column Reflux Drum	0.7	Horizontal	2.4	0.6	185	90	0.1	ss clad
D-807	C4-C5 FA Split Column Reflux Drum	0.1	Horizontal	1.2	0.3	125	34	0.01	ss clad
D-808	C3-C4 FA Product Column Reflux Drum	0.1	Horizontal	1.2	0.3	127	55	0.01	ss clad
D-809	C5-C6 FA Product Column Reflux Drum	0.4	Horizontal	1.8	0.5	183	83	0.04	ss clad
D-810	C8-C9 FA Split Column Reflux Drum	1.5	Horizontal	3	0.8	198	34	0.3	ss clad
D-811	C7-C8 FA Product Column Reflux Drum	0.7	Horizontal	2.4	0.6	192	34	0.1	ss clad
D-812	C10-C11 FA Split Column Reflux Drum	1.5	Horizontal	3	0.8	216	21	0.2	ss clad
D-813	C9-C10 FA Product Column Reflux Drum	0.7	Horizontal	2.4	0.6	210	21	0.1	ss clad
D-814	C11 FA Product Column Reflux Drum	0.2	Horizontal	0.6	0.6	314	7	0.08	ss clad

(continued)

Table 58. Cont.

Equipment ID	Equipment Name/Description	Volume (m3)	Orientation	Length (m)	Diameter (m)	Temperature (°C)	Pressure (kPa)	Flow Rate (m3/min)	MOC
D-815	Hexane Splitter Column Reflux Drum	0.4	Horizontal	1.8	0.5	35	83	0.03	Cs
D-816	Naphtha Jet Cut Column Reflux Drum	1.5	Horizontal	3	0.8	88	110	0.2	cs
D-817	Jet Diesel Cut Column Reflux Drum	4.1	Horizontal	4.3	1.1	230	90	0.6	cs
D-818	Diesel Fuel Oil Cut Column Reflux Drum	4.1	Horizontal	4.3	1.1	330	124	0.7	cs
D-819	Syngas Column Reflux Drum	2.3	Horizontal	3.6	0.9	-9	3230	0.5	cs
D-820	Debutanizer Column Reflux Drum	1.5	Horizontal	3	0.8	67	815	0.2	cs
D-821	Acetic Acid Drum	0.1	Horizontal	1.2	0.3	93	210	0.01	ss clad
D-822	Naphtha Drum	0.1	Horizontal	1.2	0.3	99	140	0.1	cs

Table 59. Extraction equipment list.

Equipment ID	Equipment Name/Description	Height (m)	Diameter (m)	Power (kW)	Residence Time (min)	Temperature (°C)	Pressure (kPa)	MOC
D-901	Fatty Acid Extractor	6.6	2.2	12	15	38	140	ss clad
D-902	Fatty Acid Separator	5.3	1.4	N/A	5	38	103	ss clad

Table 60. Knockout drum equipment list.

Equipment ID	Equipment Name/Description	Volume (m3)	Orientation	Length (m)	Diameter (m)	Temperature (°C)	Pressure (kPa)	Flow Rate (m3/min)	MOC
D-1001 A/B	Flash 3 Compressor Knockout Drum	$3x10^{-4}$	Horizontal	0.1	0.02	145	140	0.03	cs
D-1002 A/B	Stage 1 Light End Knock out Drum	2.4	Horizontal	3.1	1	21	103	110	cs
D-1003 A/B	Stage 2 Light End Knock out Drum	0.5	Horizontal	1.7	0.6	35	400	33	cs
D-1004 A/B	Stage 3 Light End Knock out Drum	0.1	Horizontal	0.9	0.3	35	1500	9	cs

Table 61. Heat exchanger equipment list.

Equipment ID	Equipment Name/Description	Area (m3)	Duty (kW)	Tube Inlet Temp (°C)	Tube Outlet Temp (°C)	Tube Pressure (kPa)	Tube MOC	Tube Fluid	Shell Inlet Temp (°C)	Shell Outlet Temp (°C)	Shell Pressure (kPa)	Shell MOC	Shell Fluid	Heat Transfer Coefficient (W/m2-°C)
E-601 A/B	Atmospheric Column Condenser	930	1950	210	55	131	cs	C4-C12 fuel intermediates	48	204	4550	cs	Boiler feed water	425
E-602 A/B	Vacuum Column Condenser	51	3100	260	220	28	cs	C12-C30 fuel intermediates	54	240	4550	cs	Boiler feed water	850
E-603 A/B	Hexane Splitter Condenser	100	97	47	35	97	cs	C1-C6 fuel intermediates	30	43	380	cs	Cooling Water	280
E-604 A/B	Naphtha Jet Cut Column Condenser	46	825	112	88	124	cs	C7-C9 fuel intermediates	30	45	380	cs	Cooling Water	280
E-605 A/B	Jet Diesel Cut Column Condenser	52	2100	243	230	104	cs	C11-C30 fuel intermediates	54	240	3340	cs	Boiler feed water	850
E-606 A/B	Diesel Fuel Oil Column Condenser	12	1770	340	330	140	cs	C16-C21 fuel intermediates	54	240	3340	cs	Boiler feed water	850
E-607 A/B	Syngas Column Condenser	230	390	8	-9	3240	cs	Syngas	-20	5	380	cs	Refrigerant	280
E-608 A/B	Debutanizer Column Condenser	99	830	69	67	830	cs	Butane	30	45	380	cs	Cooling Water	280
E-609 A/B	Water Removal Column Condenser	4540	53800	92	67	48	ss	TMA/Water	30	45	380	cs	Cooling Water	280
E-610 A/B	C2-C4 FA Split Column Condenser	1380	5500	53	51	14	ss	Acetic Acid/Water	30	45	380	cs	Cooling Water	280
E-611 A/B	Acetic Acid Column Condenser	290	3400	117	115	103	ss	Water	30	100	380	cs	Cooling Water	280
E-612 A/B	C6-C7 FA Condenser	18	600	194	185	103	ss	C3-C6 fatty acids	54	150	3170	cs	Boiler feed water	425
E-613 A/B	C4-C5 FA Condenser	3	50	130	125	41	ss	C3-C4 fatty acids	30	100	380	cs	Cooling Water	280
E-614 A/B	C3-C4 FA Condenser	3	71	130	127	69	ss	Propionic Acid	30	100	380	cs	Cooling Water	280
E-615 A/B	C5-C6 FA Condenser	9	270	184	183	97	ss	Valeric Acid	54	150	3170	cs	Boiler feed water	425
E-616 A/B	C8-C9 FA Condenser	43	1630	200	198	41	ss	C7-C8 fatty acids	54	150	3170	cs	Boiler feed water	425
E-617 A/B	C7-C8 FA Condenser	22	760	193	192	41	ss	Heptanoic Acid	54	150	3170	cs	Boiler feed water	425
E-618 A/B	C10-C11 FA Condenser	1	66	218	216	28	ss	C9-C10 fatty acids	54	204	3170	cs	Boiler feed water	425
E-619 A/B	C9-C10 FA Condenser	33	650	211	210	28	ss	Nananoic Acid	54	204	3170	cs	Boiler feed water	425

(continued)

Table 61. Cont.

Equipment ID	Equipment Name/Description	Area (m3)	Duty (kW)	Tube Inlet Temp (°C)	Tube Outlet Temp (°C)	Tube Pressure (kPa)	Tube MOC	Tube Fluid	Shell Inlet Temp (°C)	Shell Outlet Temp (°C)	Shell Pressure (kPa)	Shell MOC	Shell Fluid	Heat Transfer Coefficient (W/m2-°C)
E-620 A/B	C11 FA Condenser	18	430	216	214	14	ss	Undecanoic Acid	54	204	3170	cs	Boiler feed water	425
E-701 A/B	Cracking Cross Exchanger	320	14400	430	230	1800	ss	C1-C50 Crackate	20	310	140	cs	Soybean Oil	280
E-702 A/B	Flash 2 Cooler	170	2700	210	150	690	ss	C4-C50 fuel intermediates	54	204	4550	cs	Boiler feed water	425
E-703 A/B	Pre Flash 3 Cooler	60	250	170	38	1720	cs	C1-C7 fuel intermediates	30	150	380	cs	Cooling Water	280
E-704 A/B	Syngas Cooler	810	2400	165	32	3310	cs	C1-C5 fuel intermediates	30	15	3170	cs	Boiler feed water	425
E-705 A/B	Stage 1 Cooler	37	530	143	35	415	cs	C1-C5 fuel intermediates	30	120	380	cs	Cooling Water	280
E-706 A/B	Stage 2 Cooler	40	640	188	35	1520	cs	C1-C5 fuel intermediates	54	150	3170	cs	Boiler feed water	425
E-707 A/B	Debutanizer Cooler	12	250	180	120	3230	cs	C4-C5 fuel intermediates	54	150	3170	cs	Boiler feed water	425
E-708 A/B	C6-C7 FA Cooler	3	58	173	160	140	ss	C3-C18 fatty acids	54	150	3170	cs	Boiler feed water	425
E-709 A/B	C4-C5 FA Cooler	3	50	185	93	140	ss	C3-C6 fatty acids	54	150	3170	cs	Boiler feed water	425
E-710 A/B	C8-C9 FA Cooler	7	390	54	240	3340	ss	Boiler feed water	260	200	140	ss	C7-C18 fatty acids	850
E-711 A/B	C10-C11 FA Cooler	1	66	258	246	140	ss	C9-C18 fatty acids	54	240	3340	cs	Boiler feed water	850
E-712 A/B	C11 FA Cooler	3	200	278	226	140	ss	C11-C18 fatty acids	54	240	3340	cs	Boiler feed water	850
E-713 A/B	Flash 4 Cooler	7	560	320	176	2210	cs	C1-C17 fuel intermediates	54	240	3340	cs	Boiler feed water	850
E-714 A/B	Pre Jet Diesel Cut Cooler	3	130	54	150	4550	cs	Boiler feed water	220	210	210	cs	C11-C30 fuel intermediates	850
E-801 A/B	TTCR Preheat	290	6300	435	370	6000	ss	Superheated Steam	310	410	1930	ss	Soybean Oil	340
E-802 A/B	Atmospheric Column Preheat	35	2820	240	240	3290	ss	Medium Pressure Steam	38	135	170	cs	C4-C50 fuel intermediates	540

(continued)

Table 61. Cont.

Equipment ID	Equipment Name/Description	Area (m3)	Duty (kW)	Tube Inlet Temp (°C)	Tube Outlet Temp (°C)	Tube Pressure (kPa)	Tube MOC	Tube Fluid	Shell Inlet Temp (°C)	Shell Outlet Temp (°C)	Shell Pressure (kPa)	Shell MOC	Shell Fluid	Heat Transfer Coefficient (W/m2-°C)
E-803 A/B	C3-C4 FA Heater	1	8	125	135	140	ss	C3-C4 fatty acids	240	240	3300	cs	Medium Pressure Steam	540
E-804 A/B	Fatty Acid Decarbox Heater	6	200	280	320	3170	ss	C12-C18 fatty acids	400	370	4500	ss	High Pressure Steam	540
E-901 A/B	Atmospheric Reboiler	140	6800	400	370	5000	ss	High pressure steam	270	322	140	cs	C4-C50 fuel intermediates	540
E-902 A/B	Vacuum Column Reboiler	140	1910	400	370	5000	ss	High pressure steam	340	350	140	cs	C30-C50 fuel intermediates	340
E-903 A/B	Jet Diesel Cut Reboiler	120	3650	400	370	4500	ss	High pressure steam	290	300	117	cs	C16-C30 fuel intermediates	340
E-904 A/B	Hexane Splitter Column	24	1100	240	240	3300	ss	Medium Pressure Steam	115	141	110	cs	C5-C12 fuel intermeidates	400
E-905 A/B	Naphtha Jet Reboiler	42	1140	240	240	3300	ss	Medium Pressure Steam	180	200	160	cs	C9-C12 fuel intermediates	540
E-906 A/B	Diesel Fuel Oil Cut Reboiler	160	2200	435	370	6030	ss	Superheated Steam	390	395	170	cs	C22-C30 fuel intermediates	450
E-907 A/B	Syngas Column Reboiler	14	730	240	240	3300	ss	Medium Pressure Steam	170	180	3260	cs	C4-C5 fuel intermediates	850
E-908 A/B	Debutanizer Reboiler	8	800	240	240	3300	ss	Medium Pressure Steam	120	130	834	cs	C5-C6 fuel intermediates	850
E-909 A/B	Water Removal Reboiler	740	5600	240	240	3300	ss	Medium Pressure Steam	94	103	76	ss	C1-C18 fatty acids	540
E-910 A/B	C2-C4 FA Column Reboiler	130	5800	240	240	3300	ss	Medium Pressure Steam	133	173	21	ss	C3-C18 fatty acids	540

(continued)

Table 61. Cont.

Equipment ID	Equipment Name/Description	Area (m3)	Duty (kW)	Tube Inlet Temp (°C)	Tube Outlet Temp (°C)	Tube Pressure (kPa)	Tube MOC	Tube Fluid	Shell Inlet Temp (°C)	Shell Outlet Temp (°C)	Shell Pressure (kPa)	Shell MOC	Shell Fluid	Heat Transfer Coefficient (W/m2-°C)
E-911 A/B	Acetic Acid Column Reboiler	110	6600	240	240	3300	ss	Medium Pressure Steam	128	131	120	ss	Acetic Acid	540
E-912 A/B	C6-C7 FA Reboiler	18	1260	400	370	4500	ss	High pressure steam	245	260	124	ss	C7-C18 fatty acids	540
E-913 A/B	C4-C5 FA Reboiler	4	150	240	240	3300	ss	Medium Pressure Steam	167	168	62	ss	C5-C6 fatty acids	540
E-914 A/B	C3-C4 FA Reboiler	2	71	240	240	3300	ss	Medium Pressure Steam	150	152	83	ss	Butyric Acid	540
E-915 A/B	C5-C6 FA Product Reboiler	15	280	240	240	3300	ss	Medium Pressure Steam	200	204	110	ss	Caproic Acid	540
E-916 A/B	C8-C9 FA Reboiler	26	1900	400	370	4500	ss	High pressure steam	240	258	62	ss	C9-C18 fatty acids	540
E-917 A/B	C7-C8 FA Reboiler	45	760	240	240	3300	ss	Medium Pressure Steam	207	208	62	ss	Octanoic Acid	540
E-918 A/B	C10-C11 FA Reboiler	23	1400	400	371	4500	ss	High pressure steam	262	278	34	ss	C11-C18 fatty acids	540
E-919 A/B	C9-C10 FA Reboiler	81	650	240	240	3300	ss	Medium Pressure Steam	223	224	34	ss	Decanoic Acid	540
E-920 A/B	C11 FA Reboiler	8	560	400	370	4500	ss	Superheated Steam	254	263	21	ss	C12-C18 fatty acids	540
E-1001 A/B	Naphtha Cooler	100	320	99	32	140	cs	Naphtha product	30	45	380	cs	Cooling water	280
E-1002 A/B	Jet Cooler	330	1800	212	32	124	cs	Jet Fuel product	30	150	4550	cs	Boiler feed Water	425

(continued)

Table 61. Cont.

Equipment ID	Equipment Name/Description	Area (m3)	Duty (kW)	Tube Inlet Temp (°C)	Tube Outlet Temp (°C)	Tube Pressure (kPa)	Tube MOC	Tube Fluid	Shell Inlet Temp (°C)	Shell Outlet Temp (°C)	Shell Pressure (kPa)	Shell MOC	Shell Fluid	Heat Transfer Coefficient (W/m2-°C)
E-1003 A/B	Diesel Cooler 1	140	3600	330	60	151	ss	Diesel Fuel No. 2 product	54	240	3340	cs	Boiler feed water	850
E-1004 A/B	Diesel Cooler 2	150	280	60	35	210	cs	Diesel Fuel No. 2 product	30	55	380	cs	Cooling Water	280
E-1005 A/B	Fuel Oil Cooler	3	42	395	60	140	ss	Fuel Oil No. 5	54	240	3340	cs	Boiler feed water	280

Table 62. Compressor equipment list.

Equipment ID	Equipment Name/Description	Stages	Inlet Pressure (kPa)	Outlet Pressure (kPa)	Inlet Temp (°C)	Outlet Temp (°C)	Flow Rate (m3/min)	Power (kW)	MOC	Fluid
G-201 A/B	Flash 2 Compressor	One	140	420	145	200	38	17	ss	Light Ends
G-202 A/B	Flash 3 Compressor	One	103	1650	171	243	38	1	cs	Light Ends
G-203 Stage 1	Light End Compressor	Three	103	415	21	143	745	500	cs	Light Ends
G-203 Stage 2	Light End Compressor	Three	400	1520	35	188	745	500	cs	Light Ends
G-203 Stage 3	Light End Compressor	Three	1500	3310	35	166	745	500	cs	Light Ends

Table 63. Pumps equipment list.

Equipment ID	Equipment Name/Description	Power (kW)	Inlet Pressure (kPa)	Outlet Pressure (kPa)	Temp (°C)	Fluid	MOC
L-201 A/B	PreCracking Pump	54	103	1930	310	Soybean Oil	ss
L-203 A/B	Post Extractor Pump	1	104	170	38	C4-C50 fuel intermediates	ss
L-204 A/B	Atmospheric Reflux	2	97	140	55	C4-C12 fuel intermediates	cs
L-205 A/B	Vacuum Reflux	5	7	41	220	C12-C30 fuel intermediates	cs
L-206 A/B	Vacuum Bottoms	1	34	140	340	Vacuum Bottoms	cs
L-209 A/B	Syngas Column Reflux	5	3210	3260	-9	Syngas	cs
L-210 A/B	Debutanizer Reflux	2	790	840	67	Butane	cs
L-211 A/B	Hexane Splitter Bottoms	1	83	170	141	C5-C12 fuel intermediates	cs
L-212 A/B	Hexane Splitter Reflux	2	62	140	35	C1-C6 fuel intermediates	cs
L-213 A/B	Naphtha Reflux	5	90	150	88	C7-C9 fuel intermediates	cs
L-214 A/B	Pre Jet Pump	2	140	210	210	C11-C30 fuel intermediates	cs
L-215 A/B	Jet Reflux	4	69	124	230	C11-C30 fuel intermediates	Cs
L-216 A/B	Jet Bottoms	1	83	170	300	C16-C30 fuel intermediates	cs
L-217 A/B	Diesel Reflux	8	104	150	330	C16-C21 fuel intermediates	cs
L-218 A/B	Water Removal Reflux	5	14	76	67	TMA/Water	ss
L-219 A/B	Water Removal Bottoms	1	55	140	103	C1-C18 fatty acids	ss

(continued)

Table 63. Cont.

Equipment ID	Equipment Name/Description	Power (kW)	Inlet Pressure (kPa)	Outlet Pressure (kPa)	Temp (°C)	Fluid	MOC
L-220 A/B	Solvent Recycle Pump	2	76	140	67	TMA/Water	Ss
L-221 A/B	Acetic Acid Reflux	6	69	140	115	Water	ss
L-222 A/B	C3 FA Bottoms	1	7	140	173	C3-C18 fatty acids	ss
L-223 A/B	C3 FA Reflux	5	3	28	51	Acetic Acid/Water	ss
L-224 A/B	C6-C7 FA Reflux	7	69	140	185	C3-C6 fatty acids	ss
L-225 A/B	C6-C7 FA Bottom	1	97	140	260	C7-C18 fatty acids	ss
L-226 A/B	C4-C5 FA Reflux	7	21	48	125	C3-C4 fatty acids	ss
L-227 A/B	C4-C5 FA Bottom	1	41	140	168	C5-C6 fatty acids	ss
L-228 A/B	C3-C4 FA Reflux	6	34	90	261	Propionic Acid	ss
L-229 A/B	C3-C4 FA Bottom	1	55	170	152	Butyric Acid	ss
L-230 A/B	C5-C6 FA Bottom	1	83	170	204	Caproic Acid	ss
L-231 A/B	C5-C6 FA Reflux	6	62	110	183	Valeric Acid	ss
L-232 A/B	C8-C9 FA Bottom	1	41	140	258	C9-C18 fatty acids	ss
L-233 A/B	C8-C9 FA Reflux	5	21	55	198	C7-C8 fatty acids	ss
L-234 A/B	C7-C8 FA Bottom	1	34	170	208	Octanoic Acid	ss
L-235 A/B	C7-C8 FA Reflux	5	21	55	192	Heptanoic Acid	ss
L-236 A/B	C10-C11 FA Bottom	1	14	140	278	C11-C18 fatty acids	ss
L-237 A/B	C10-C11 FA Reflux	6	7	41	216	C9-C10 fatty acids	ss
L-239 A/B	C9-10 FA Bottoms	1	14	170	224	Decanoic Acid	Ss
L-240 A/B	C11 FA Reflux	5	3	21	214	Undecanoic Acid	ss
L-241 A/B	C11 FA Bottoms	7	7	3170	263	C12-C18 fatty acids	ss

(continued)

Table 63. Cont.

Equipment ID	Equipment Name/Description	Power (kW)	Inlet Pressure (kPa)	Outlet Pressure (kPa)	Temp (°C)	Fluid	MOC
L-242 A/B	Jet Product	1	90	170	32	Jet Fuel Product	Cs
L-243 A/B	Diesel Product	1	117	210	60	Diesel Fuel Oil No. 2 Product	cs
L-244 A/B	C9-C10 FA Reflux	5	7	41	210	Nananoic Acid	ss
L-245 A/B	Post Extractor Pump 2	1	104	140	38	C3-C18 fatty acids	ss
L-246 A/B	Atmospheric Top Pump	2	97	210	55	C4-C12 fuel intermediates	cs
L-247 A/B	Vacuum Top Pump	3	7	140	220	C12-C30 fuel intermediates	cs
L-248 A/B	Naphtha Product	1	104	170	32	Naphtha Product	cs
L-249 A/B	C2-C4 FA Split Top	1	3	110	51	Acetic Acid/Water	ss
L-250 A/B	C4-C5 FA Split Top	1	21	140	125	C3-C4 fatty acids	ss
L-251 A/B	C3-C4 FA Product Top	1	34	170	127	Butyric Acid	ss
L-252 A/B	C5-C6 FA Product Top	1	62	170	183	Valeric Acid	ss
L-253 A/B	C8-C9 FA Split Top	1	21	103	198	C7-C8 fatty acids	ss
L-254 A/B	C7-C8 FA Product Top	1	21	170	192	Heptanoic Acid	ss
L-255 A/B	C10-C11 FA Split Top	1	7	103	216	C9-C10 fatty acids	ss
L-256 A/B	C9-C10 FA Split Top	1	7	170	210	Nananoic Acid	ss
L-257 A/B	C11 FA Top	2.5	3	170	217	Undecanoic Acid	ss
L-258 A/B	Flash 3 Pump	1	103	170	21	C5-C7 fuel intermediates	cs
L-259 A/B	Pre Jet Diesel Pump 2	1	104	170	170	C11-C17 fuel intermediates	cs

Table 64. Reactor equipment list.

Equipment ID	Equipment Name/Description	Diameter (m)	Length (m)	Tubes	Catalyst (m3)	Residence Time (hr)	Temperature (°C)	Pressure (kPa)	MOC
R-201	TTCR	6.1	12.2	10300	N/A	1.17	430	1800	cs/inconel
R-202 A/B	Fatty Acid Decarboxylation Reactor	1.8	11.2	N/A	62	3.2	320	2200	ss clad

Table. 65. Drawing number codes and corresponding definitions for the fatty acid recovery design.

Code	**Definition**
00	Entire Plant
01	Thermal Cracking Section
02	Purification Section
03	Decarboxylation Section
04	Trim Purification Section
05	Light End Processing
07	Fatty Acid Recovery Section
A	11x17" Drawing Size
010	Fatty Acid Recovery Input/Output Diagram - Metric Units
011	Fatty Acid Recovery Design Block Flow Diagram - Metric Units
012	Fatty Acid Recovery Design Process Flow Diagram - Metric Units

Table 66. Drawing naming system using example number 00-A-001/1.

Code	00	A	001	/1
Definition	Plant Section	Drawing Size	Drawing Type	Sheet

Table 67. Broad cost estimate for the fatty acid recovery design.

Equipment	Equipment Description	Number	Capacity/Size Specs	Purchased Equipment Cost: Basis Date: Year 2004	Purchased Equipment Cost: Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-601	Flash 1	1	Height: 5.8 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$17,500	$24,000	2.5	1	7	$160,000	$160,000
D-602	Flash 2	1	Height: 5.8 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$17,500	$24,000	2.5	1	7	$160,000	$160,000
D-603	Flash 3	1	Height: 2 m Inside Diameter: 1.2 m Vertical Orientation MOC: Carbon Steel	$6,500	$8,700	1	2	6	$52,000	$52,000
D-604	Acetic Acid Separator 1	1	Height: 1.8 m Inside Diameter: 0.5 m Vertical Orientation MOC: Stainless Steel Clad	$3,500	$4,700	2.5	1.5	7	$33,000	$33,000
D-605	Acetic Acid Separator 2	1	Height: 3.4 m Inside Diameter: 0.8 m Vertical Orientation MOC: Stainless Steel Clad	$10,000	$13,000	2.5	1	4	$54,000	$54,000
D-606	Flash 4	1	Height: 2.8 m Inside Diameter: 0.8 m Vertical Orientation MOC: Carbon Steel	$9,000	$12,000	1	1	4	$48,000	$48,000
D-607	Flash 5	1	Height: 2.8 m Inside Diameter: 0.8 m Vertical Orientation MOC: Carbon Steel	$9,000	$12,000	1	1.5	5	$60,000	$60,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-701	Atmospheric Column	1	Height: 8.2 m Diameter: 2.1 m Trays: 7 Feed: Tray 5 MOC: Carbon Steel	$30,000	$40,000	1	1	4	$160,000	$160,000
D-701 Trays	Atmospheric Column Trays	7	Diameter: 2.1 m MOC: Stainless Steel	From Quote	$2,300	1	1	1.2	$2,800	$20,000
D-702	Vacuum Column	1	Height: 21.8 m Diameter: 4.4 m Trays: 20 Feed: Tray 10 MOC: Carbon Steel	$125,000	$170,000	1	1	4	$670,000	$670,000
D-702 Trays	Vacuum Column Trays	20	Diameter: 4.4 m MOC: Stainless Steel	From Quote	$3,600	1	1	1.2	$4,300	$86,000
D-703	Water Removal Column	1	Height: 18.8 m Diameter: 2.2 m Trays: 19 Feed: Tray 12 MOC: Stainless Steel Clad	$65,000	$87,000	2.5	1	7	$610,000	$610,000
D-703 Trays	Water Removal Column Trays	19	Diameter: 2.2 m MOC: Stainless Steel	From Quote	$2,400	1	1	1.2	$2,900	$54,000
D-704	C2-C4 FA Split Column	1	Height: 19 m Diameter: 1.6 m Trays: 20 Feed: Tray 16 MOC: Stainless Steel Clad	$50,000	$67,000	2.5	1	7	$470,000	$470,000
D-704 Trays	C2-C4 FA Split Column Trays	20	Diameter: 1.6 m MOC: Stainless Steel	From Quote	$1,900	1	1	1.2	$2,300	$46,000
D-705	Acetic Acid Column	1	Height: 20.7 m Diameter: 1.5 m Trays: 22 Feed: Tray 12 MOC: Stainless Steel Clad	$50,000	$67,000	2.5	1	7	$470,000	$470,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-705 Trays	Acetic Acid Column Trays	22	Diameter: 1.5 m MOC: Stainless Steel	From Quote	$1,900	1	1	1.2	$2,300	$50,000
D-706	C6-C7 FA Split Column	1	Height: 31.5 m Diameter: 1.1 m Trays: 35 Feed: Tray 15 MOC: Stainless Steel Clad	$70,000	$94,000	2.5	1	7	$660,000	$660,000
D-706 Trays	C6-C7 FA Split Column Trays	35	Diameter: 1.1 m MOC: Stainless Steel	From Quote	$1,500	1	1	1.2	$1,800	$65,000
D-707	C4-C5 FA Split Column	1	Height: 28.3 m Diameter: 0.4 m Trays: 32 Feed: Tray 12 MOC: Stainless Steel Clad	$70,000	$94,000	2.5	1	7	$660,000	$660,000
D-707 Trays	C4-C5 FA Split Column Trays	32	Diameter: 0.4 m MOC: Stainless Steel	From Quote	$930	1	1	1.2	$1,100	$36,000
D-708	C3-C4 FA Product Column	1	Height: 24.7 m Diameter: 0.3 m Trays: 28 Feed: Tray 15 MOC: Stainless Steel Clad	$35,000	$47,000	2.5	1	7	$330,000	$330,000
D-708 Trays	C3-C4 Product Column Trays	28	Diameter: 0.3 m MOC: Stainless Steel	From Quote	$730	1	1	1.2	$870	$24,000
D-709	C5-C6 FA Product Column	1	Height: 26.7 m Diameter: 0.6 m Trays: 30 Feed: Tray 15 MOC: Stainless Steel Clad	$35,000	$47,000	2.5	1	7	$330,000	$330,000
D-709 Trays	C5-C6 Product Column Trays	30	Diameter: 0.6 m MOC: Stainless Steel	From Quote	$1,100	1	1	1.2	$1,300	$40,000
D-710	C8-C9 FA Split Column	1	Height: 24.7 m Diameter: 2.1 m Trays: 26 Feed: Tray 15 MOC: Stainless Steel Clad	$80,000	$110,000	2.5	1	7	$750,000	$750,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-710 Trays	C8-C9 Split Column Trays	26	Diameter: 2.1 m MOC: Stainless Steel	From Quote	$2,300	1	1	1.2	$2,800	$72,000
D-711	C7-C8 FA Product Column	1	Height: 25.7 m Diameter: 1.3 m Trays: 28 Feed: Tray 15 MOC: Stainless Steel Clad	$60,000	$81,000	2.5	1	7	$560,000	$560,000
D-711 Trays	C7-C8 Product Column Trays	28	Diameter: 1.3 m MOC: Stainless Steel	From Quote	$1,700	1	1	1.2	$2,100	$57,000
D-712	C10-C11 FA Split Column	1	Height: 30.3 m Diameter: 2.4 m Trays: 32 Feed: Tray 19 MOC: Stainless Steel Clad	$150,000	$200,000	2.5	1	7	$1,400,000	$1,400,000
D-712 Trays	C10-C11 Split Column Trays	32	Diameter: 2.4 m MOC: Stainless Steel	From Quote	$2,500	1	1	1.2	$3,000	$96,000
D-713	C9-C10 FA Product Column	1	Height: 29.4 m Diameter: 1.5 m Trays: 32 Feed: Tray 17 MOC: Stainless Steel Clad	$90,000	$120,000	2.5	1	7	$850,000	$850,000
D-713 Trays	C9-C10 Product Column Trays	32	Diameter: 1.5 m MOC: Stainless Steel	From Quote	$1,900	1	1	1.2	$2,300	$72,000
D-714	C11 FA Product Column	1	Height: 27.8 m Diameter: 1.7 m Trays: 30 Feed: Tray 17 MOC: Stainless Steel Clad	$85,000	$110,000	2.5	1	7	$800,000	$800,000
D-714 Trays	C11 Product Column Trays	30	Diameter: 1.7 m MOC: Stainless Steel	From Quote	$2,000	1	1	1.2	$2,400	$73,000
D-715	Hexane Splitter Column	1	Height: 7.9 m Diameter: 0.9 m Trays: 8 Feed: Trays 3 and 4 MOC: Carbon Steel	$20,000	$27,000	1	1	4	$110,000	$110,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-715 Trays	Hexane Splitter Column Trays	8	Diameter: 0.9 m MOC: Stainless Steel	From Quote	$1,000	1	1	1.2	$1,200	$9,900
D-716	Naphtha Jet Cut Column	1	Height: 27.7 m Diameter: 1.6 m Trays: 30 Feed: Tray 7 MOC: Carbon Steel	$100,000	$130,000	1	1	4	$540,000	$540,000
D-716 Trays	Naphtha Jet Cut Column Trays	30	Diameter: 1.6 m MOC: Stainless Steel	From Quote	$2,000	1	1	1.2	$2,400	$71,000
D-717	Jet Diesel Cut Column	1	Height: 24.8 m Diameter: 3.0 m Trays: 25 Feed: Tray 13 MOC: Carbon Steel	$125,000	$170,000	1	1	4	$670,000	$670,000
D-717 Trays	Jet Diesel Cut Column Trays	25	Diameter: 3.0 m MOC: Stainless Steel	From Quote	$2,900	1	1	1.2	$3,400	$86,000
D-718	Diesel Fuel Oil Cut Column	1	Height: 47.9 m Diameter: 4.3 m Trays: 50 Feed: Tray 23 MOC: Carbon Steel	$250,000	$340,000	1	1	4	$1,300,000	$1,300,000
D-718 Trays	Diesel Fuel Oil Cut Column Trays	50	Diameter: 4.3 m MOC: Stainless Steel	From Quote	$3,600	1	1	1.2	$4,300	$210,000
D-719	Syngas Column	1	Height: 37.1 m Diameter: 0.2 m Trays: 40 Feed: Tray 15 MOC: Carbon Steel	$30,000	$40,000	1	3	8	$320,000	$320,000
D-719 Trays	Syngas Column Trays	40	Diameter: 0.2 m MOC: Stainless Steel	From Quote	$500	1	3	1.2	$1,800	$73,000
D-720	Debutanizer Column	1	Height: 11.2 m Diameter: 0.9 m Trays: 12 Feed: Tray 8 MOC: Carbon Steel	$25,000	$34,000	1	1.5	5	$170,000	$170,000

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Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-720 Trays	Debutanizer Column Trays	12	Diameter: 0.9 m MOC: Stainless Steel	From Quote	$1,400	1	2	1.2	$3,300	$39,000
D-801	Atmospheric Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	$2,500	$3,400	1	1	3	$10,000	$10,000
D-802	Vacuum Column Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	$6,000	$8,100	1	1	3	$24,000	$24,000
D-803	Water Removal Column Reflux Drum	1	Length: 5.5 m Inside Diameter: 1.4 m Horizontal Orientation MOC: Stainless Steel Clad	$10,000	$13,000	2.5	1	4	$54,000	$54,000
D-804	C2-C4 FA Split Column Reflux Drum	1	Length: 2.4 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Stainless Steel Clad	$2,000	$2,700	2.5	1	4	$11,000	$11,000
D-805	Acetic Acid Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$2,500	$3,400	2.5	1	4	$13,000	$13,000
D-806	C6-C7 FA Split Column Reflux Drum	1	Length: 2.4 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Stainless Steel Clad	$2,000	$2,700	2.5	1	4	$11,000	$11,000
D-807	C4-C5 FA Split Column Reflux Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Stainless Steel Clad	$1,000	$1,300	2.5	1	4	$5,400	$5,400
D-808	C3-C4 FA Product Column Reflux Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Stainless Steel Clad	$1,000	$1,300	2.5	1	4	$5,400	$5,400

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-809	C5-C6 FA Product Column Reflux Drum	1	Length: 1.8 m Inside Diameter: 0.5 m Horizontal Orientation MOC: Stainless Steel Clad	$1,500	$2,000	2.5	1	4	$8,100	$8,100
D-810	C8-C9 FA Split Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$2,500	$3,400	2.5	1	4	$13,000	$13,000
D-811	C7-C8 FA Product Column Reflux Drum	1	Length: 2.4 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Stainless Steel Clad	$2,000	$2,700	2.5	1	4	$11,000	$11,000
D-812	C10-C11 FA Split Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$2,500	$3,400	2.5	1	4	$13,000	$13,000
D-813	C9-C10 FA Product Column Reflux Drum	1	Length: 2.4 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Stainless Steel Clad	$2,000	$2,700	2.5	1	4	$11,000	$11,000
D-814	C11 FA Product Column Reflux Drum	1	Length: 2.4 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Stainless Steel Clad	$2,000	$2,700	2.5	1	4	$11,000	$11,000
D-815	Hexane Splitter Column Reflux Drum	1	Length: 1.8 m Inside Diameter: 0.5 m Horizontal Orientation MOC: Carbon Steel	$1,500	$2,000	1	1	3	$6,000	$6,000
D-816	Naphtha Jet Cut Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	$2,500	$3,400	1	1	3	$10,000	$10,000
D-817	Jet Diesel Cut Column Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	$6,000	$8,100	1	1	3	$24,000	$24,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-818	Diesel Fuel Oil Cut Column Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	$6,000	$8,100	1	1	3	$24,000	$24,000
D-819	Syngas Column Reflux Drum	1	Length: 3.6 m Inside Diameter: 0.9 m Horizontal Orientation MOC: Carbon Steel	$4,000	$5,400	1	3	6	$32,000	$32,000
D-820	Debutanizer Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	$2,500	$3,400	1	1.5	4	$13,000	$13,000
D-821	Acetic Acid Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Stainless Steel Clad	$2,500	$3,400	2.5	1	4	$13,000	$13,000
D-822	Naphtha Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Carbon Steel	$2,500	$3,400	1	1.5	4	$13,000	$13,000
D-901	Fatty Acid Extractor	2	Height: 6.6 m Diameter: 2.2 m Residence Time: 15 min MOC: Stainless Steel Clad	$25,000	$34,000	2.5	1	7	$240,000	$470,000
D-902	Fatty Acid Separator	1	Height: 5.3 m Diameter: 1.4 m MOC: Stainless Steel Clad	$17,500	$24,000	2.5	1	7	$160,000	$160,000
D-1001 A/B	Flash 3 Compressor Knockout Drum	2	Height: 0.1 m Inside Diameter: 0.02 m Horizontal Orientation MOC: Carbon Steel	$1,000	$1,300	1	1	3	$4,000	$8,100
D-1002 A/B	Stage 1 Light End Knock out Drum	2	Height: 3.1 m Inside Diameter: 1.0 m Horizontal Orientation MOC: Carbon Steel	$5,000	$6,700	1	1	3	$20,000	$40,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-1003 A/B	Stage 2 Light End Knock out Drum	2	Height: 1.7 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Carbon Steel	$1,750	$2,400	1	1.5	4	$9,400	$19,000
D-1004 A/B	Stage 3 Light End Knock out Drum	2	Height: 0.9 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Carbon Steel	$1,000	$1,300	1	3	6	$8,100	$16,000
E-601 A/B	Atmospheric Column Condenser	2	Surface Area: 930 m2 Heat Duty: 1950 kW MOC (shell/tube): cs/cs	$40,000	$54,000	1	1	3	$160,000	$320,000
E-602 A/B	Vacuum Column Condenser	2	Surface Area: 51 m2 Heat Duty: 3100 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3	$40,000	$81,000
E-603 A/B	Hexane Splitter Condenser	2	Surface Area: 100 m2 Heat Duty: 97 kW MOC (shell/tube): cs/cs	$15,000	$20,000	1	1	3	$60,000	$120,000
E-604 A/B	Naphtha Jet Cut Column Condenser	2	Surface Area: 46 m2 Heat Duty: 825 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3	$40,000	$81,000
E-605 A/B	Jet Diesel Cut Column Condenser	2	Surface Area: 52 m2 Heat Duty: 2100 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3	$40,000	$81,000
E-606 A/B	Diesel Fuel Oil Column Condenser	2	Surface Area: 12 m2 Heat Duty: 1770 kW MOC (shell/tube): cs/cs	$5,000	$6,700	1	1	3	$20,000	$40,000
E-607 A/B	Syngas Column Condenser	2	Surface Area: 230 m2 Heat Duty: 390 kW MOC (shell/tube): cs/cs	$25,000	$34,000	1	1.1	3.5	$120,000	$240,000
E-608 A/B	Debutanizer Column Condenser	2	Surface Area: 99 m2 Heat Duty: 830 kW MOC (shell/tube): cs/cs	$15,000	$20,000	1	1.1	3.5	$71,000	$140,000
E-609 A/B	Water Removal Column Condenser	2	Surface Area: 4540 m2 Heat Duty: 53800 kW MOC (shell/tube): cs/ss	$150,000	$200,000	1.7	1	4	$810,000	$1,600,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-610 A/B	C2-C4 FA Split Column Condenser	2	Surface Area: 1380 m2 Heat Duty: 5500 kW MOC (shell/tube): cs/ss	$70,000	$94,000	1.7	1	4	$380,000	$750,000
E-611 A/B	Acetic Acid Column Condenser	2	Surface Area: 290 m2 Heat Duty: 3400 kW MOC (shell/tube): cs/ss	$30,000	$40,000	1.7	1	4	$160,000	$320,000
E-612 A/B	C6-C7 FA Condenser	2	Surface Area: 18 m2 Heat Duty: 600 kW MOC (shell/tube): cs/ss	$6,000	$8,100	1.7	1	4	$32,000	$64,000
E-613 A/B	C4-C5 FA Condenser	2	Surface Area: 3 m2 Heat Duty: 50 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000
E-614 A/B	C3-C4 FA Condenser	2	Surface Area: 3 m2 Heat Duty: 71 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000
E-615 A/B	C5-C6 FA Condenser	2	Surface Area: 9 m2 Heat Duty: 270 kW MOC (shell/tube): cs/ss	$5,000	$6,700	1.7	1	4	$27,000	$54,000
E-616 A/B	C8-C9 FA Condenser	2	Surface Area: 43 m2 Heat Duty: 1630 kW MOC (shell/tube): cs/ss	$10,000	$13,000	1.7	1	4	$54,000	$110,000
E-617 A/B	C7-C8 FA Condenser	2	Surface Area: 22 m2 Heat Duty: 760 kW MOC (shell/tube): cs/ss	$6,500	$8,700	1.7	1	4	$35,000	$70,000
E-618 A/B	C10-C11 FA Condenser	2	Surface Area: 1 m2 Heat Duty: 66 kW MOC (shell/tube): cs/ss	$2,000	$2,700	1.7	1	4	$11,000	$21,000
E-619 A/B	C9-C10 FA Condenser	2	Surface Area: 33 m2 Heat Duty: 650 kW MOC (shell/tube): cs/ss	$7,000	$9,400	1.7	1	4	$38,000	$75,000
E-620 A/B	C11 FA Condenser	2	Surface Area: 18 m2 Heat Duty: 430 kW MOC (shell/tube): cs/ss	$6,500	$8,700	1.7	1	4	$35,000	$70,000
E-701 A/B	Cracking Cross Exchanger	2	Surface Area: 320 m2 Heat Duty: 14400 kW MOC (shell/tube): cs/ss	$30,000	$40,000	1.7	1.1	4.25	$170,000	$340,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-702 A/B	Flash 2 Cooler	2	Surface Area: 170 m2 Heat Duty: 2700 kW MOC (shell/tube): cs/ss	$20,000	$27,000	1.7	1	4	$110,000	$210,000
E-703 A/B	Pre Flash 3 Cooler	2	Surface Area: 60 m2 Heat Duty: 250 kW MOC (shell/tube): cs/cs	$10,250	$14,000	1	1	3	$41,000	$83,000
E-704 A/B	Syngas Cooler	2	Surface Area: 810 m2 Heat Duty: 2400 kW MOC (shell/tube): cs/cs	$60,000	$81,000	1	1.1	3.5	$280,000	$560,000
E-705 A/B	Stage 1 Cooler	2	Surface Area: 37 m2 Heat Duty: 530 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3	$40,000	$81,000
E-706 A/B	Stage 2 Cooler	2	Surface Area: 40 m2 Heat Duty: 640 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1.1	3.5	$47,000	$94,000
E-707 A/B	Debutanizer Cooler	2	Surface Area: 12 m2 Heat Duty: 250 kW MOC (shell/tube): cs/cs	$6,000	$8,100	1	1.1	3.5	$28,000	$56,000
E-708 A/B	C6-C7 FA Cooler	2	Surface Area: 3 m2 Heat Duty: 58 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000
E-709 A/B	C4-C5 FA Cooler	2	Surface Area: 3 m2 Heat Duty: 50 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000
E-710 A/B	C8-C9 FA Cooler	2	Surface Area: 7 m2 Heat Duty: 390 kW MOC (shell/tube): cs/ss	$5,000	$6,700	1.7	1	4	$27,000	$54,000
E-711 A/B	C10-C11 FA Cooler	2	Surface Area: 1 m2 Heat Duty: 66 kW MOC (shell/tube): cs/ss	$2,000	$2,700	1.7	1	4	$11,000	$21,000
E-712 A/B	C11 FA Cooler	2	Surface Area: 3 m2 Heat Duty: 200 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-713 A/B	Flash 4 Cooler	2	Surface Area: 7 m2 Heat Duty: 560 kW MOC (shell/tube): cs/cs	$5,000	$6,700	1	1	3	$20,000	$40,000
E-714 A/B	Pre Jet Diesel Cut Cooler	2	Surface Area: 3 m2 Heat Duty: 130 kW MOC (shell/tube): cs/cs	$3,000	$4,000	1	1	3	$12,000	$24,000
E-801 A/B	TTCR Preheat	2	Surface Area: 290 m2 Heat Duty: 6300 kW MOC (shell/tube): ss/ss	$30,000	$40,000	3	1.1	6	$240,000	$480,000
E-802 A/B	Atmospheric Column Preheat	2	Surface Area: 35 m2 Heat Duty: 2820 kW MOC (shell/tube): cs/ss	$9,500	$13,000	1.7	1	4	$51,000	$100,000
E-803 A/B	C3-C4 FA Heater	2	Surface Area: 1 m2 Heat Duty: 8 kW MOC (shell/tube): cs/ss	$2,000	$2,700	1.7	1	4	$11,000	$21,000
E-804 A/B	Fatty Acid Decarbox Heater	2	Surface Area: 6 m2 Heat Duty: 200 kW MOC (shell/tube): ss/ss	$4,000	$5,400	3	1.1	6	$32,000	$64,000
E-901 A/B	Atmospheric Reboiler	2	Surface Area: 140 m2 Heat Duty: 6800 kW MOC (shell/tube): cs/ss	$18,000	$24,000	1.7	1	4	$97,000	$190,000
E-902 A/B	Vacuum Column Reboiler	2	Surface Area: 140 m2 Heat Duty: 1910 kW MOC (shell/tube): cs/ss	$18,000	$24,000	1.7	1	4	$97,000	$190,000
E-903 A/B	Jet Diesel Cut Reboiler	2	Surface Area: 120 m2 Heat Duty: 3650 kW MOC (shell/tube): cs/ss	$12,000	$16,000	1.7	1	4	$64,000	$130,000
E-904 A/B	Hexane Splitter Column	2	Surface Area: 24 m2 Heat Duty: 1100 kW MOC (shell/tube): cs/ss	$6,500	$8,700	1.7	1	4	$35,000	$70,000
E-905 A/B	Naphtha Jet Reboiler	2	Surface Area: 42 m2 Heat Duty: 1140 kW MOC (shell/tube): cs/ss	$10,000	$13,000	1.7	1	4	$54,000	$110,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-906 A/B	Diesel Fuel Oil Cut Reboiler	2	Surface Area: 160 m2 Heat Duty: 2200 kW MOC (shell/tube): cs/ss	$20,000	$27,000	1.7	1	4	$110,000	$210,000
E-907 A/B	Syngas Column Reboiler	2	Surface Area: 14 m2 Heat Duty: 730 kW MOC (shell/tube): cs/ss	$6,000	$8,100	1.7	1.1	4.25	$34,000	$69,000
E-908 A/B	Debutanizer Reboiler	2	Surface Area: 8 m2 Heat Duty: 800 kW MOC (shell/tube): cs/ss	$5,000	$6,700	1.7	1.1	4.25	$29,000	$57,000
E-909 A/B	Water Removal Reboiler	2	Surface Area: 740 m2 Heat Duty: 5600 kW MOC (shell/tube): ss/ss	$50,000	$67,000	3	1	6	$400,000	$810,000
E-910 A/B	C2-C4 FA Column Reboiler	2	Surface Area: 130 m2 Heat Duty: 5800 kW MOC (shell/tube): ss/ss	$17,500	$24,000	3	1	6	$140,000	$280,000
E-911 A/B	Acetic Acid Column Reboiler	2	Surface Area: 110 m2 Heat Duty: 6600 kW MOC (shell/tube): ss/ss	$15,000	$20,000	3	1	6	$120,000	$240,000
E-912 A/B	C6-C7 FA Reboiler	2	Surface Area: 18 m2 Heat Duty: 1260 kW MOC (shell/tube): ss/ss	$6,000	$8,100	3	1	6	$48,000	$97,000
E-913 A/B	C4-C5 FA Reboiler	2	Surface Area: 4 m2 Heat Duty: 150 kW MOC (shell/tube): ss/ss	$3,000	$4,000	3	1	6	$24,000	$48,000
E-914 A/B	C3-C4 FA Reboiler	2	Surface Area: 2 m2 Heat Duty: 71 kW MOC (shell/tube): ss/ss	$2,000	$2,700	3	1	6	$16,000	$32,000
E-915 A/B	C5-C6 FA Product Reboiler	2	Surface Area: 15 m2 Heat Duty: 280 kW MOC (shell/tube): ss/ss	$6,000	$8,100	3	1	6	$48,000	$97,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-916 A/B	C8-C9 FA Reboiler	2	Surface Area: 26 m2 Heat Duty: 1900 kW MOC (shell/tube): ss/ss	$7,000	$9,400	3	1	6	$56,000	$110,000
E-917 A/B	C7-C8 FA Reboiler	2	Surface Area: 45 m2 Heat Duty: 760 kW MOC (shell/tube): ss/ss	$9,500	$13,000	3	1	6	$77,000	$150,000
E-918 A/B	C10-C11 FA Reboiler	2	Surface Area: 23 m2 Heat Duty: 1400 kW MOC (shell/tube): ss/ss	$6,000	$8,100	3	1	6	$48,000	$97,000
E-919 A/B	C9-C10 FA Reboiler	2	Surface Area: 81 m2 Heat Duty: 650 kW MOC (shell/tube): ss/ss	$12,500	$17,000	3	1	6	$100,000	$200,000
E-920 A/B	C11 FA Reboiler	2	Surface Area: 8 m2 Heat Duty: 560 kW MOC (shell/tube): ss/ss	$7,000	$9,400	3	1	6	$56,000	$110,000
E-1001 A/B	Naphtha Cooler	2	Surface Area: 100 m2 Heat Duty: 320 kW MOC (shell/tube): cs/cs	$15,000	$20,000	1	1	3	$60,000	$120,000
E-1002 A/B	Jet Cooler	2	Surface Area: 330 m2 Heat Duty: 1800 kW MOC (shell/tube): cs/cs	$35,000	$47,000	1	1	3	$140,000	$280,000
E-1003 A/B	Diesel Cooler 1	2	Surface Area: 140 m2 Heat Duty: 3600 kW MOC (shell/tube): cs/ss	$20,000	$27,000	1.7	1	4	$110,000	$210,000
E-1004 A/B	Diesel Cooler 2	2	Surface Area: 150 m2 Heat Duty: 280 kW MOC (shell/tube): cs/cs	$20,000	$27,000	1	1	3	$81,000	$160,000
E-1005 A/B	Fuel Oil Cooler	2	Surface Area: 3 m2 Heat Duty: 42 kW MOC (shell/tube): cs/ss	$4,000	$5,400	1.7	1	4	$21,000	$43,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
G-201 A/B	Flash 2 Compressor	2	Power: 17 kW Number of Stages: 1 MOC: Stainless Steel	From Quote	$18,000	1	1	2.5	$45,000	$91,000
G-202 A/B	Flash 3 Compressor	2	Power: 1 kW Number of Stages: 1 MOC: Carbon Steel	From Quote	$55	1	1	2.5	$140	$280
G-203	Light End Compressor	1	Power: 1500 kW Number of Stages: 3 MOC: Carbon Steel	From Quote	$1,600,000	1	1	2.5	$4,100,000	$4,100,000
L-201 A/B	PreCracking Pump	2	Power: 54 kW Suction Pressure: 110 kPa MOC: Stainless Steel	$17,500	$24,000	1.9	1	5	$120,000	$240,000
L-203 A/B	Post Extractor Pump	2	Power: 1 kW Suction Pressure: 140 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	6	$24,000	$48,000
L-204 A/B	Atmospheric Reflux	2	Power: 2 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	4	$27,000	$54,000
L-205 A/B	Vacuum Reflux	2	Power: 5 kW Suction Pressure: 7 kPa MOC: Carbon Steel	$6,000	$8,100	1.4	1	4	$32,000	$64,000
L-206 A/B	Vacuum Bottoms	2	Power: 1 kW Suction Pressure: 40 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-207 A/B	Naphtha Cut Pump	2	Power: 1 kW Suction Pressure: 130 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-208 A/B	Flash 5 Pump	2	Power: 1 kW Suction Pressure: 102 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-209 A/B	Syngas Column Reflux	2	Power: 5 kW Suction Pressure: 3200 kPa MOC: Carbon Steel	$6,000	$8,100	1.4	1.75	6	$48,000	$97,000
L-210 A/B	Debutanizer Reflux	2	Power: 2 kW Suction Pressure: 790 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	4	$27,000	$54,000
L-211 A/B	Hexane Splitter Bottoms	2	Power: 1 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-212 A/B	Hexane Splitter Reflux	2	Power: 2 kW Suction Pressure: 90 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	4	$27,000	$54,000
L-213 A/B	Naphtha Reflux	2	Power: 5 kW Suction Pressure: 90 kPa MOC: Carbon Steel	$6,000	$8,100	1.4	1	4	$32,000	$64,000
L-214 A/B	Pre Jet Pump	2	Power: 2 kW Suction Pressure: 102 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	4	$27,000	$54,000
L-215 A/B	Jet Reflux	2	Power: 4 kW Suction Pressure: 68 kPa MOC: Carbon Steel	$5,500	$7,400	1.4	1	4	$30,000	$59,000
L-216 A/B	Jet Bottoms	2	Power: 1 kW Suction Pressure: 110 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-217 A/B	Diesel Reflux	2	Power: 8 kW Suction Pressure: 102 kPa MOC: Carbon Steel	$8,000	$11,000	1.4	1	4	$43,000	$86,000
L-218 A/B	Water Removal Reflux	2	Power: 5 kW Suction Pressure: 14 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-219 A/B	Water Removal Bottoms	2	Power: 1 kW Suction Pressure: 69 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-220 A/B	Solvent Recycle Pump	2	Power: 2 kW Suction Pressure: 69 kPa MOC: Stainless Steel	$5,000	$6,700	1.9	1	5	$34,000	$67,000
L-221 A/B	Acetic Acid Reflux	2	Power: 6 kW Suction Pressure: 69 kPa MOC: Stainless Steel	$7,000	$9,400	1.9	1	5	$47,000	$94,000
L-222 A/B	C3 FA Bottoms	2	Power: 1 kW Suction Pressure: 14 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-223 A/B	C3 FA Reflux	2	Power: 5 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-224 A/B	C6-C7 FA Reflux	2	Power: 7 kW Suction Pressure: 69 kPa MOC: Stainless Steel	$7,500	$10,000	1.9	1	5	$50,000	$100,000
L-225 A/B	C6-C7 FA Bottoms	2	Power: 1 kW Suction Pressure: 116 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-226 A/B	C4-C5 FA Reflux	2	Power: 7 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$7,500	$10,000	1.9	1	5	$50,000	$100,000
L-227 A/B	C4-C5 FA Bottoms	2	Power: 1 kW Suction Pressure: 55 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-228 A/B	C3-C4 FA Reflux	2	Power: 6 kW Suction Pressure: 34 kPa MOC: Stainless Steel	$7,000	$9,400	1.9	1	5	$47,000	$94,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-229 A/B	C3-C4 FA Bottoms	2	Power: 1 kW Suction Pressure: 55 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-230 A/B	C5-C6 FA Bottoms	2	Power: 1 kW Suction Pressure: 82 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-231 A/B	C5-C6 FA Reflux	2	Power: 6 kW Suction Pressure: 62 kPa MOC: Stainless Steel	$7,000	$9,400	1.9	1	5	$47,000	$94,000
L-232 A/B	C8-C9 FA Bottoms	2	Power: 1 kW Suction Pressure: 41 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-233 A/B	C8-C9 FA Reflux	2	Power: 5 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-234 A/B	C7-C8 FA Bottoms	2	Power: 1 kW Suction Pressure: 34 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-235 A/B	C7-C8 FA Reflux	2	Power: 5 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-236 A/B	C10-C11 FA Bottoms	2	Power: 1 kW Suction Pressure: 14 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-237 A/B	C10-C11 FA Reflux	2	Power: 6 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$7,000	$9,400	1.9	1	5	$47,000	$94,000
L-238 A/B	C9-C10 FA Reflux	2	Power: 5 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-239 A/B	C9-10 FA Bottoms	2	Power: 1 kW Suction Pressure: 14 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-240 A/B	C11 FA Reflux	2	Power: 5 kW Suction Pressure: 4 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-241 A/B	C11 FA Bottoms	2	Power: 7 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$7,500	$10,000	1.9	1	5	$50,000	$100,000
L-242 A/B	Jet Product	2	Power: 1 kW Suction Pressure: 69 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-243 A/B	Diesel Product	2	Power: 1 kW Suction Pressure: 102 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-244 A/B	C9-C10 FA Reflux	2	Power: 5 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-245 A/B	Post Extractor Pump 2	2	Power: 1 kW Suction Pressure: 102 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-246 A/B	Atmospheric Top Pump	2	Power: 2 kW Suction Pressure: 96 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	4	$27,000	$54,000
L-247 A/B	Vacuum Top Pump	2	Power: 3 kW Suction Pressure: 7 kPa MOC: Carbon Steel	$4,000	$5,400	1.4	1	4	$21,000	$43,000
L-248 A/B	Naphtha Product	2	Power: 1 kW Suction Pressure: 102 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-249 A/B	C2-C4 FA Split Top	2	Power: 1 kW Suction Pressure: 3 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-250 A/B	C4-C5 FA Split Top	2	Power: 1 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-251 A/B	C3-C4 FA Product Top	2	Power: 1 kW Suction Pressure: 34 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-252 A/B	C5-C6 FA Product Top	2	Power: 1 kW Suction Pressure: 161 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-253 A/B	C8-C9 FA Split Top	2	Power: 1 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-254 A/B	C7-C8 FA Product Top	2	Power: 1 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-255 A/B	C10-C11 FA Split Top	2	Power: 1 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-256 A/B	C9-C10 FA Split Top	2	Power: 1 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-257 A/B	C11 FA Top	2	Power: 2.5 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$5,500	$7,400	1.9	1	5	$37,000	$74,000
L-258 A/B	Flash 3 Pump	2	Power: 1 kW Suction Pressure: 105 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-259 A/B	Pre Jet Diesel Pump 2	2	Power: 1 kW Suction Pressure: 104 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
P-201	Refrigeration System	1	Load: 820-890 metric tons Power: 200 Volts	From Quote	$1,800,000	1	1	3.2	$5,900,000	$5,900,000
Q-201	TTCR Boiler	1	Duty: 64,000 kW	From Quote	$2,000,000	1	1	3.2	$6,500,000	$6,500,000

(continued)

Table 67. Broad cost estimate for fatty acid recovery design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
Q-202	High Pressure Steam Boiler	1	Duty: 41,000 kW	From Quote	$1,600,000	1	1	3.2	$5,000,000	$5,000,000
R-201	TTCR	1	Diameter: 6.1 m Length: 12.2 m Tubes: 10300 MOC: cs/inconel	From Quote	$30,000,000	0.7	1	3.2	$21,000,000	$21,000,000
R-202 A/B	Fatty Acid Decarboxylation Reactor	2	Diameter: 1.8 m Length: 11.2 m MOC: Stainless Steel Clad	From Quote	$390,000	1	1	3.2	$390,000	$780,000

Total Bare Module Cost	CTBM	$ 72,000,000
Contingency and Fee	CTBM*0.18	$ 13,000,000
Total Module Cost	CTM	$85,000,000
Auxiliary Facilities	CTM*0.2	$ 17,000,000
Fixed Capital Investment	FCI	$ 100,000,000
Working Capital	FCI*0.15	$ 15,000,000
Chemicals & Catalysts		$ 2,700,000
Total Capital Investment	TCI	$ 120,000,000

Notes: Actual numbers may be off due to rounding

Table 68. Operating expense summary for fatty acid recovery design.

Year	Chemicals and Catalysts	Operating Labor	Maintenance	Utilities	Yearly Total
1	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000
2	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000
3	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000
4	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000
5	$2,200,000	$4,000,000	$6,100,000	$7,600,000	$20,000,000
6	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000
7	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000
8	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000
9	$2,200,000	$4,000,000	$6,100,000	$7,600,000	$20,000,000
10	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000
11	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000
12	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000
13	$2,200,000	$4,000,000	$6,100,000	$7,600,000	$20,000,000
14	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000
15	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000
16	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000
17	$2,200,000	$4,000,000	$6,100,000	$7,600,000	$20,000,000
18	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000
19	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000
20	$170,000	$4,000,000	$6,100,000	$7,600,000	$18,000,000

Notes: Actual numbers may be off due to rounding

Table 69. Cash flow sheet for fatty acid recovery design.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR	Present Value @ DCFROR
-1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	($51,000)	($51,000)	($57,000)	($74,000)
0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	($69,000)	($69,000)	($69,000)	($69,000)
1	$420,000	$300,000	$18,000	$100,000	$(14,000)	$88,000	$(36,000)		$66,000	$59,000	$45,000
2	$420,000	$300,000	$18,000	$100,000	$(12,000)	$89,000	$(37,000)		$65,000	$52,000	$31,000
3	$420,000	$300,000	$18,000	$100,000	$(11,000)	$91,000	$(38,000)		$64,000	$46,000	$21,000
4	$420,000	$300,000	$18,000	$100,000	$(9,700)	$92,000	$(38,000)		$64,000	$40,000	$14,000
5	$420,000	$300,000	$20,000	$100,000	$(8,600)	$91,000	$(38,000)		$62,000	$35,000	$9,700
6	$420,000	$300,000	$18,000	$100,000	$(7,600)	$94,000	$(39,000)		$63,000	$32,000	$6,800
7	$420,000	$300,000	$18,000	$100,000	$(6,700)	$95,000	$(39,000)		$62,000	$28,000	$4,700
8	$420,000	$300,000	$18,000	$100,000	$(5,900)	$96,000	$(40,000)		$62,000	$25,000	$3,200
9	$420,000	$300,000	$20,000	$100,000	$(5,200)	$95,000	$(39,000)		$61,000	$22,000	$2,200
10	$420,000	$300,000	$18,000	$100,000	$(4,900)	$97,000	$(40,000)		$62,000	$20,000	$1,500
11	$420,000	$300,000	$18,000	$100,000	$(4,900)	$97,000	$(40,000)		$62,000	$18,000	$1,100
12	$420,000	$300,000	$18,000	$100,000	$(4,900)	$97,000	$(40,000)		$62,000	$16,000	$730
13	$420,000	$300,000	$20,000	$100,000	$(4,900)	$95,000	$(39,000)		$60,000	$14,000	$490
14	$420,000	$300,000	$18,000	$100,000	$(4,900)	$97,000	$(40,000)		$62,000	$13,000	$350
15	$420,000	$300,000	$18,000	$100,000	$(4,900)	$97,000	$(40,000)		$62,000	$11,000	$240
16	$420,000	$300,000	$18,000	$100,000	$(4,900)	$97,000	$(40,000)		$62,000	$10,000	$170
17	$420,000	$300,000	$20,000	$100,000	$(4900)	$95,000	$(39,000)		$60,000	$8,800	$110
18	$420,000	$300,000	$18,000	$100,000		$100,000	$(42,000)		$60,000	$7,800	$76
19	$420,000	$300,000	$18,000	$100,000		$100,000	$(42,000)		$60,000	$6,900	$53
20	$420,000	$300,000	$18,000	$100,000		$100,000	$(42,000)	$15,000	$75,000	$7,800	$46
									NPA@HR	$340,000	$0
									DCFROR	45%	
									HR	12%	

Notes: Dollar values are in thousands

Actual numbers may be off due to rounding

Numbers in parenthesis represent negative numbers

Table 70. Cash flow sheet for fatty acid recovery design and a soybean oil price of $0.76/kg.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR
-1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	($51,000)	($51,000)	($57,000)
0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	($69,000)	($69,000)	($69,000)
1	$420,000	$380,000	$18,000	$23,000	($14,000)	$8,900	($3,700)		$19,000	$17,000
2	$420,000	$380,000	$18,000	$23,000	($12,000)	$11,000	($4,400)		$19,000	$15,000
3	$420,000	$380,000	$18,000	$23,000	($11,000)	$12,000	($5,000)		$18,000	$13,000
4	$420,000	$380,000	$18,000	$23,000	($9,700)	$13,000	($5,500)		$18,000	$11,000
5	$420,000	$380,000	$20,000	$21,000	($8,600)	$12,000	($5,100)		$16,000	$9,000
6	$420,000	$380,000	$18,000	$23,000	($7,600)	$16,000	($6,400)		$17,000	$8,400
7	$420,000	$380,000	$18,000	$23,000	($6,700)	$16,000	($6,800)		$16,000	$7,400
8	$420,000	$380,000	$18,000	$23,000	($5,900)	$17,000	($7,100)		$16,000	$6,500
9	$420,000	$380,000	$20,000	$21,000	($5,200)	$16,000	($6,500)		$14,000	$5,200
10	$420,000	$380,000	$18,000	$23,000	($4,900)	$18,000	($7,500)		$16,000	$5,000
11	$420,000	$380,000	$18,000	$23,000	($4,900)	$18,000	($7,500)		$16,000	$4,500
12	$420,000	$380,000	$18,000	$23,000	($4,900)	$18,000	($7,500)		$16,000	$4,000
13	$420,000	$380,000	$20,000	$21,000	($4,900)	$16,000	($6,700)		$14,000	$3,300
14	$420,000	$380,000	$18,000	$23,000	($4,900)	$18,000	($7,500)		$16,000	$3,200
15	$420,000	$380,000	$18,000	$23,000	($4,900)	$18,000	($7,500)		$16,000	$2,800
16	$420,000	$380,000	$18,000	$23,000	($4,900)	$18,000	($7,500)		$16,000	$2,500
17	$420,000	$380,000	$20,000	$21,000	($4,900)	$16,000	($6,700)		$14,000	$2,100
18	$420,000	$380,000	$18,000	$23,000	$ -	$23,000	($9,600)		$14,000	$1,800
19	$420,000	$380,000	$18,000	$23,000	$ -	$23,000	($9,600)		$14,000	$1,600
20	$420,000	$380,000	$18,000	$23,000	$ -	$23,000	($9,600)	$15,000	$29,000	$3,000
									NPV@HR	$0
									DCFROR	12%
									HR	12%

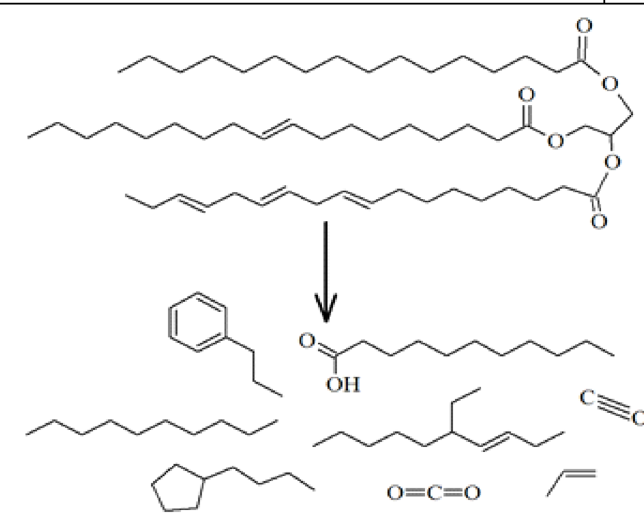
Notes: Dollar values are in thousands

Actual numbers may be off due to rounding

Numbers in parenthesis represent negative numbers

Soybean Oil: 600 m^3/year

Steam: 270 m^3/year



Syn Gas: 1,300 N km^3/year

Butane: 22 liquid km^3/year

Petroleum Naphtha: 79 liquid km^3/year

Jet Fuel: 190 liquid km^3/year

Diesel Fuel No. 2: 260 liquid km^3/year

Fatty Acid Products C2-C11

See Note 2

Vacuum Bottoms: 230 liquid km^3/year

Fuel Oi No. 5: 2.5 liquid km^3/year

Fatty Acid	Liquid km^3/year
Acetic Acid	3.2
Propionic Acid	0.37
Butyric Acid	0.75
Valeric Acid	2.3
Caproic Acid	4.5
Heptanoic Acid	12
Octanoic Acid	8.7
Nananoic Acid	9.8
Decanoic Acid	9.3
Undecanoic Acid	3.7

Notes

1. Material balance may be off due to rounding errors.

2. See table below for fatty acid product production.

Special Symbols / Nomenclature

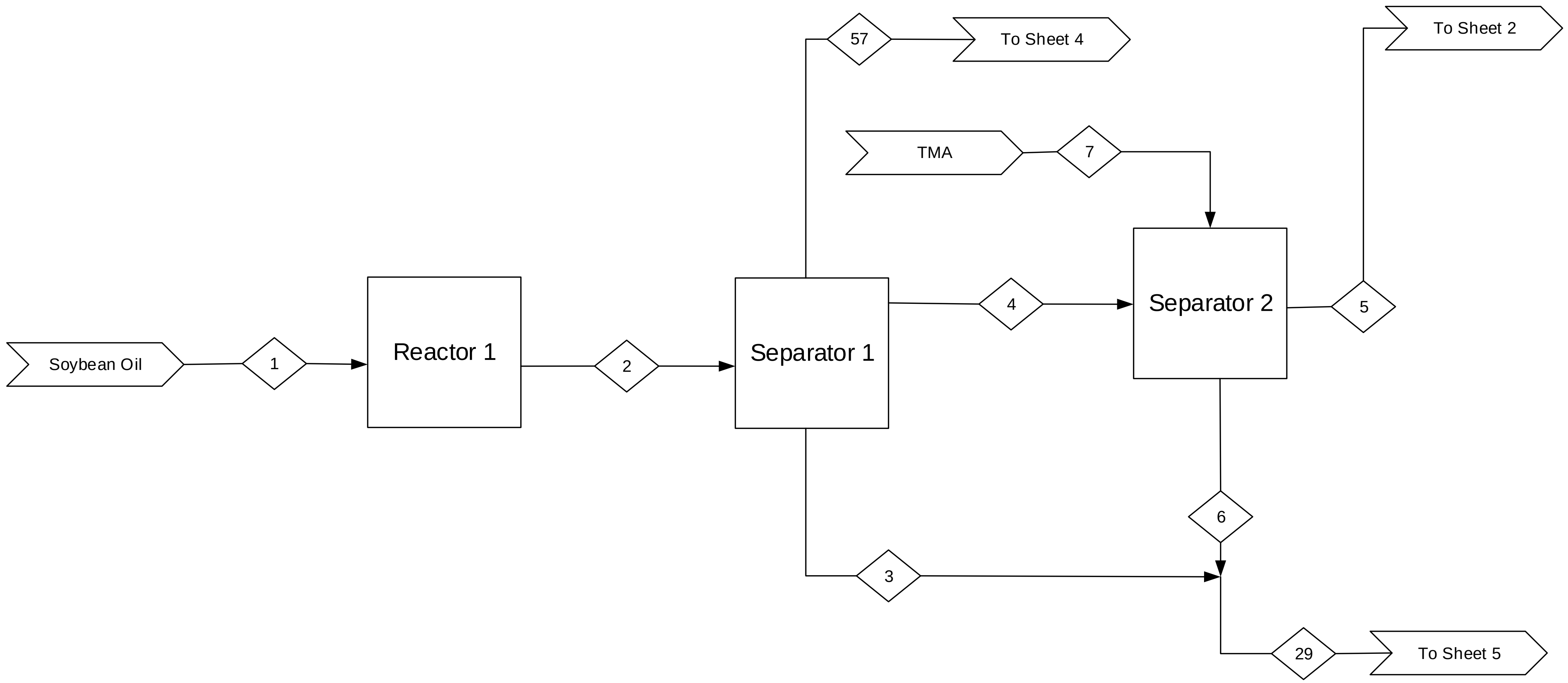
Reference Drawings:
Block Flow Diagram
00-A-011

Process Flow Diagram
00-A-012

Drawing Type
Input/Output Diagram

Title
Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 2/14/17	00-A-010/1	0



Component/Stream (kg/min)	1	2	3	4	5	6	7	29	57
Soybean Oil	1000	0	0	0	0	0	0	0	0
C1-C50	0	1000	0	820	640	0	0	0	0
Fatty Acids C2-C17	0	0	0	0	0	130	0	130	0
Acetic Acid	0	0	3	0	0	2	0	5	0
C1-C6	0	0	0	0	0	0	0	0	160
TMA	0	0	0	0	0	150	150	150	0
Water	0	0	0	0	0	620	620	620	0
Total	1000	1000	3	820	640	910	770	910	160

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 1: Cracking incoming TG oil into fuel intermediates

Separator 1: Separate aqueous acetic acid from organic crackate

Separator 2: Separate fatty acids from organic liquid product through solvent extraction

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-010

Process Flow Diagram
00-A-012

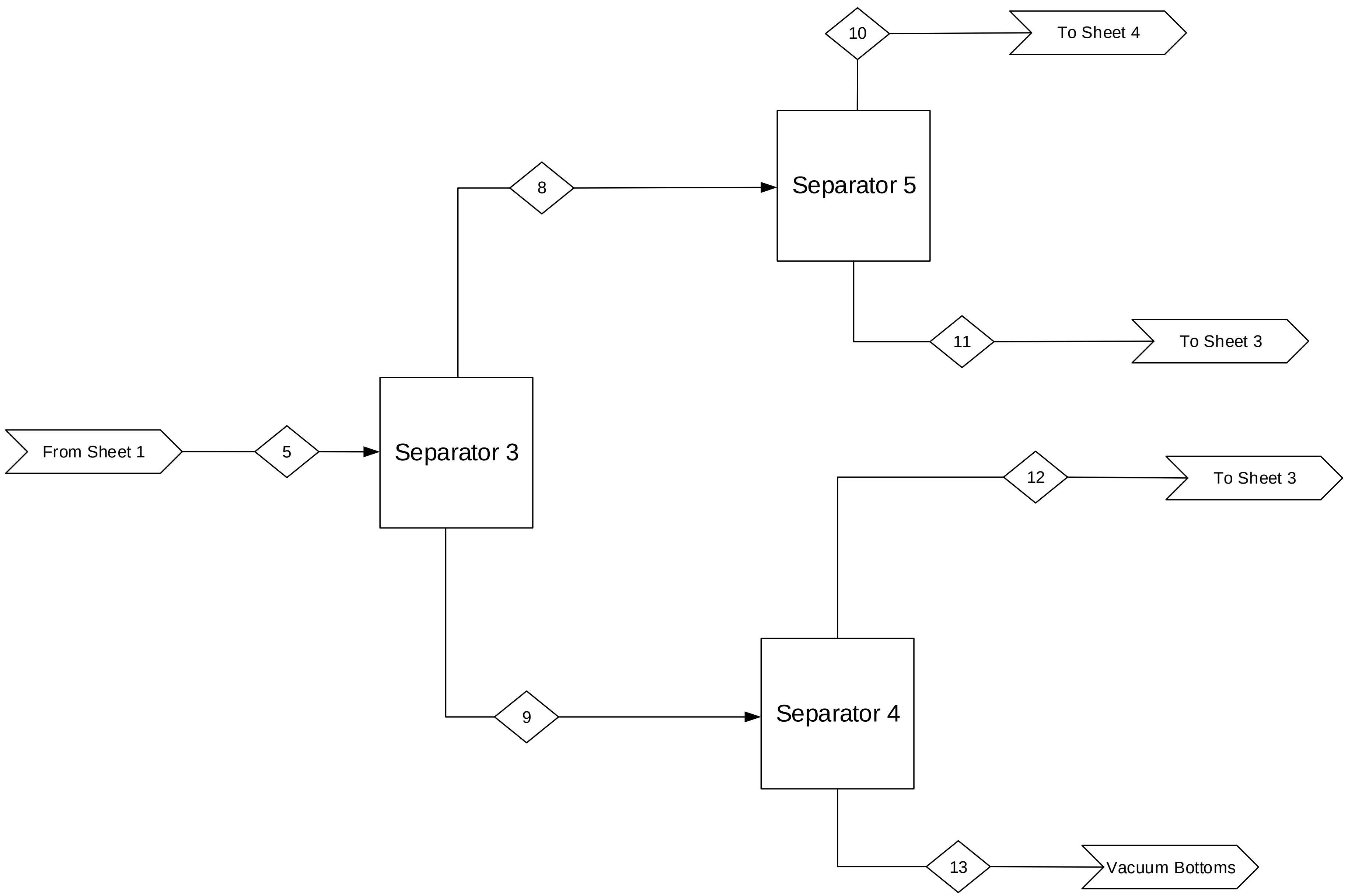
Drawing Type

Quantitative BFD

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 2-15-17	00-A-011/1	0



Component/Stream (kg/min)	5	8	9	10	11	12	13
C1-C50	640	0	0	0	0	0	0
C9-C50	0	0	500	0	0	0	0
C1-C15	0	200	0	0	0	0	0
C1-C5	0	0	0	6	0	0	0
C5-C15	0	0	0	0	200	0	0
C9-C30	0	0	0	0	0	250	0
C30-C50	0	0	0	0	0	0	250
Total	640	200	500	6	200	250	250

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

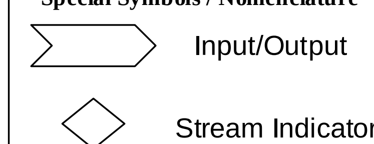
6. Assume 100% separation in separators.

7. Separator 3: Separate naphtha range fuel intermediates from diesel range fuel intermediates

Separator 4: Separate diesel fuel range intermediates from vacuum bottoms byproduct

Separator 5: Separate light ends from naphtha range fuel intermediates

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagram
00-A-010

Process Flow Diagram
00-A-012

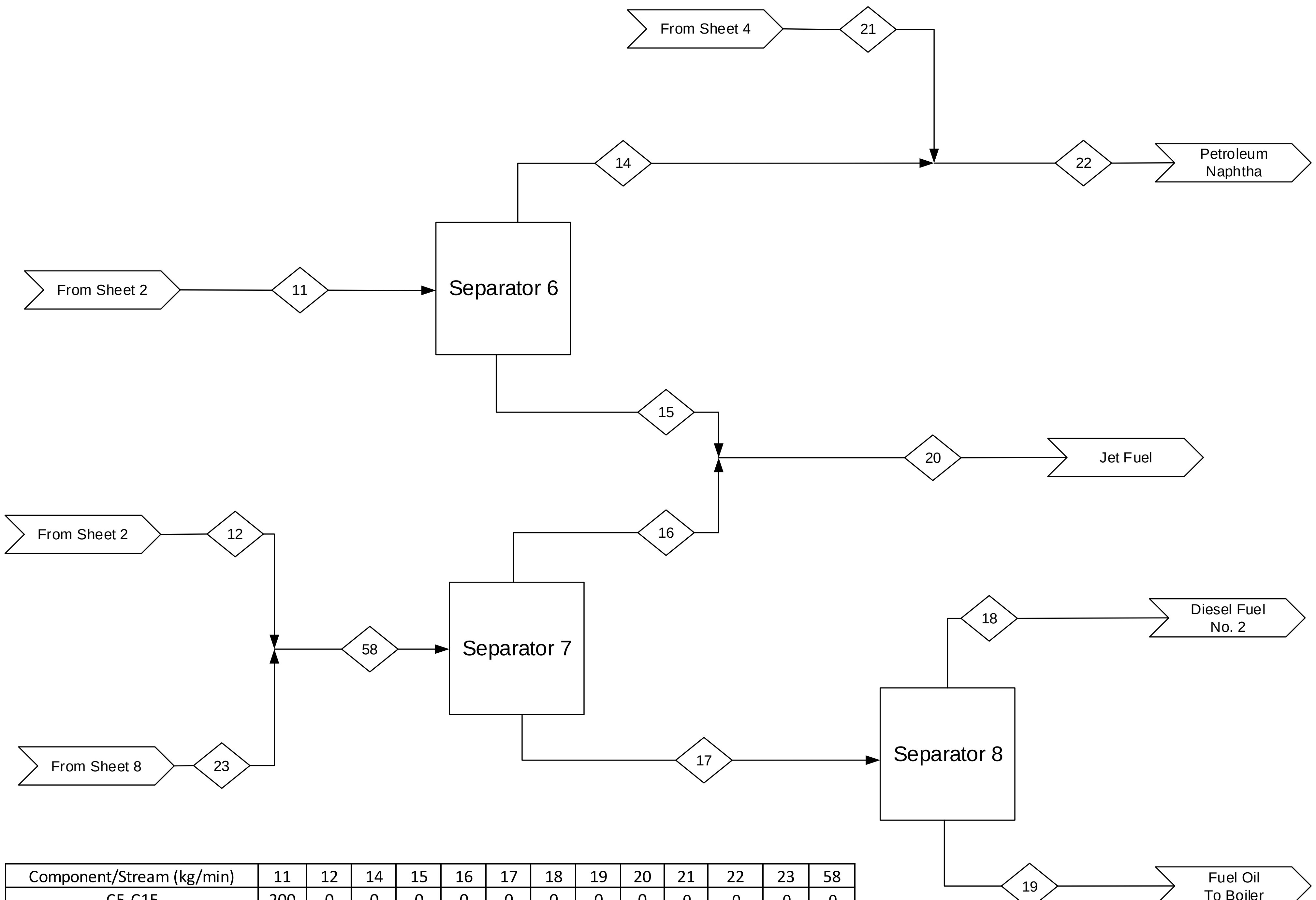
Drawing Type

Quantitative BFD

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 2-15-17	00-A-011/2	0



Component/Stream (kg/min)	11	12	14	15	16	17	18	19	20	21	22	23	58
C5-C15	200	0	0	0	0	0	0	0	0	0	0	0	0
C5-C8	0	0	45	0	0	0	0	0	0	39	86	0	0
C9-C15	0	0	0	150	64	0	0	0	210	0	0	50	0
C15-C22	0	0	0	0	0	0	240	0	0	0	0	0	0
C15-C30	0	0	0	0	0	240	0	0	0	0	0	0	0
C23-C30	0	0	0	0	0	0	0	2	0	0	0	0	0
C9-C30	0	250	0	0	0	0	0	0	0	0	0	0	300
Total	200	250	45	150	64	240	240	2	210	39	86	50	300

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Separator 6: Separate naphtha product from jet fuel product

Separator 7: Separate jet fuel product from diesel and fuel oil range intermediates

Separator 8: Separate diesel fuel no. 2 product from fuel oil no. 5 by product

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-010

Process Flow Diagram
00-A-012

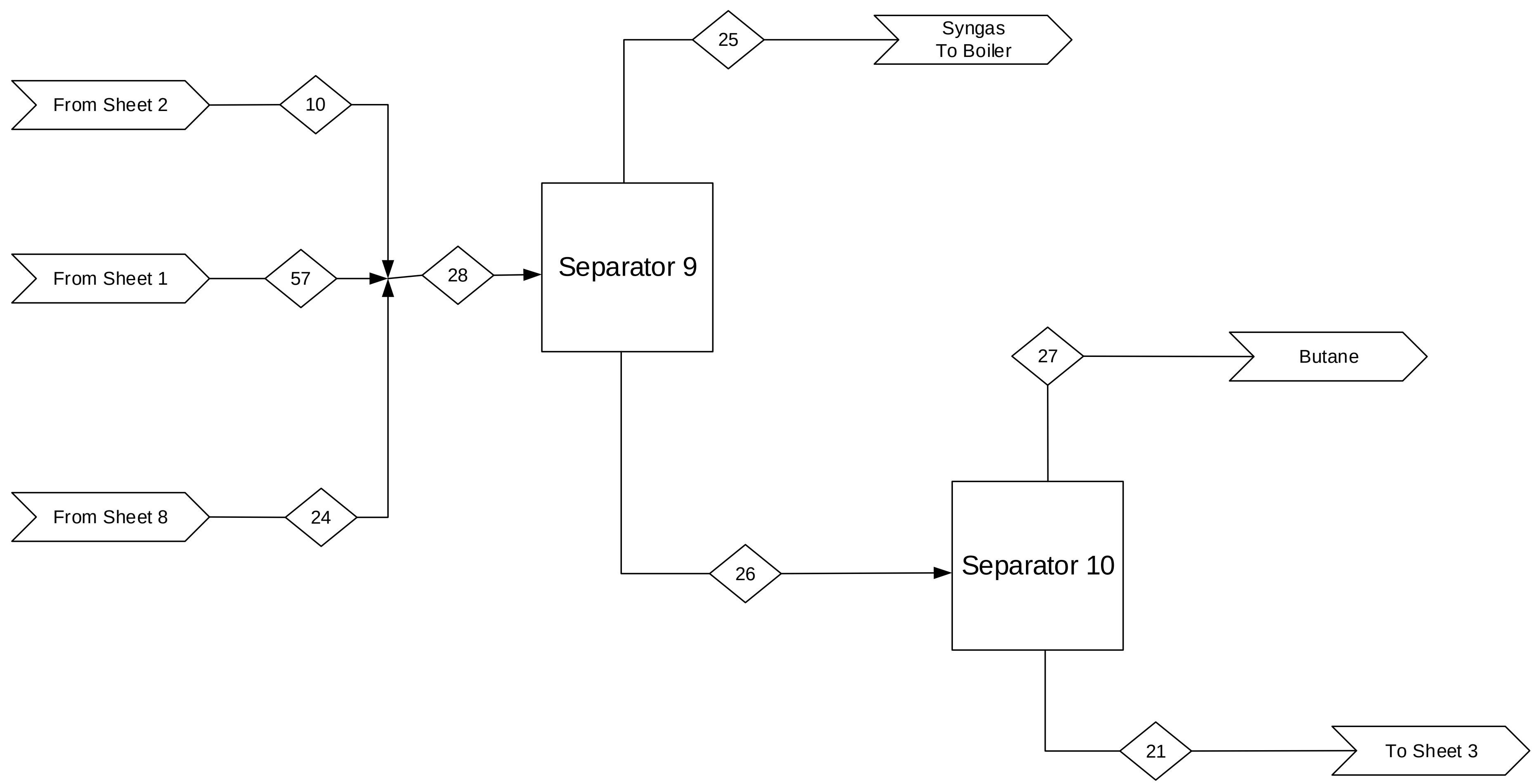
Drawing Type

Quantitative BFD

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 02-15-17	00-A-011/3	0



Component/Stream (kg/min)	10	21	24	25	26	27	28	57
C1-C6	0	0	0	0	0	0	0	160
C1-C10	0	0	14	0	0	0	180	0
C1-C3	0	0	0	120	0	0	0	0
Butane	0	0	0	0	0	19	0	0
C4-C10	0	0	0	0	59	0	0	0
C5-C10	0	39	0	0	0	0	0	0
C1-C5	6	0	0	0	0	0	0	0
Total	6	39	14	120	59	19	180	160

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Separator 9: Separate boiler fuel (syngas) from heavier light ends

Separator 10. Separate butane byproduct from naphtha product

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-010

Process Flow Diagram
00-A-012

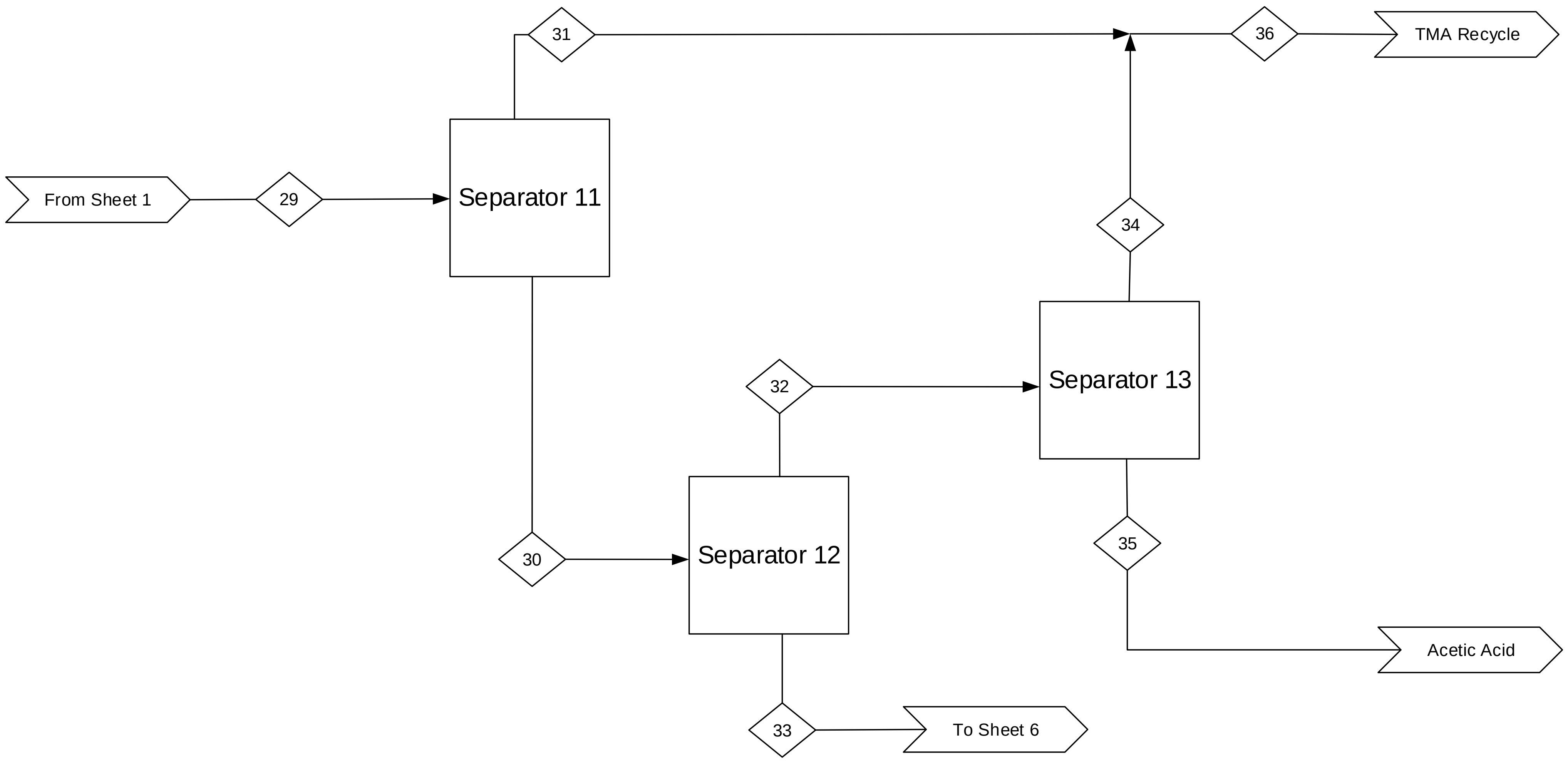
Drawing Type

Quantitative BFD

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 02-15-17	00-A-011/4	0



Component/Stream (kg/min)	29	30	31	32	33	34	35	36
TMA	150	0	150	0	0	0	0	150
Water	620	31	590	31	0	31	0	620
Fatty Acids C2-C17	0	0	0	0	0	0	0	0
Fatty Acids C3-C17	130	130	0	0	130	0	0	0
Acetic Acid	5	5	0	5	0	0	5	0
Total	910	160	730	36	130	31	5	770

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

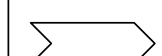
6. Assume 100% separation in separators.

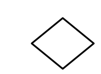
7. Separator 11: Removes all of the solvent and the majority of water from the fatty acids

Separator 12: Separates remaining water and acetic acid from heavier fatty acids

Separator 13. Separates acetic acid by product from water

Special Symbols / Nomenclature

 Input/Output

 Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-010

Process Flow Diagram
00-A-012

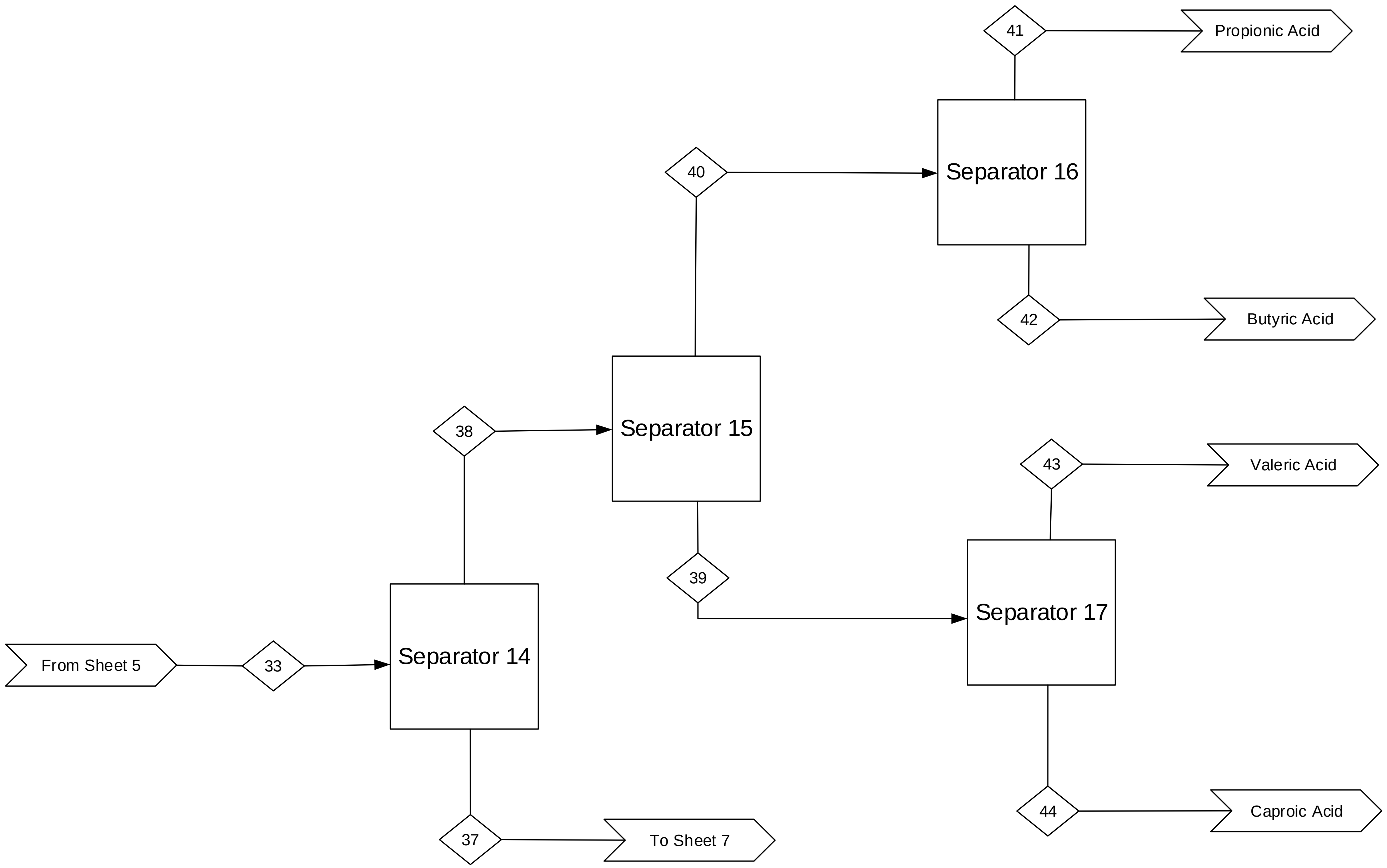
Drawing Type

Quantitative BFD

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 02-15-17	00-A-011/5	0



Component/Stream (kg/min)	33	37	38	39	40	41	42	43	44
Fatty Acids C3-C17	130	0	0	0	0	0	0	0	0
Fatty Acids C3-C6	0	0	10	0	0	0	0	0	0
Fatty acids C7-C17	0	120	0	0	0	0	0	0	0
Fatty Acids C3-C4	0	0	0	0	2	0	0	0	0
Propionic Acid	0	0	0	0	0	1	0	0	0
Butyric Acid	0	0	0	0	0	0	1	0	0
Fatty Acids C5-C6	0	0	0	9	0	0	0	0	0
Valeric Acid	0	0	0	0	0	0	0	3	0
Caproic Acid	0	0	0	0	0	0	0	0	5
Total	130	120	10	9	2	1	1	3	5

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

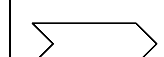
7. Separator 14: Separate C6 and lighter fatty acids from C7 and heavier fatty acids

Separator 15: Separate C3-C4 fatty acids from C5-C6 fatty acids

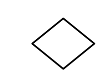
Separator 16: Separate propionic acid byproduct from butyic acid byproduct

Separator 17: Separate valeric acid byproduct from caproic acid byproduct

Special Symbols / Nomenclature



Input/Output



Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-010

Process Flow Diagram
00-A-012

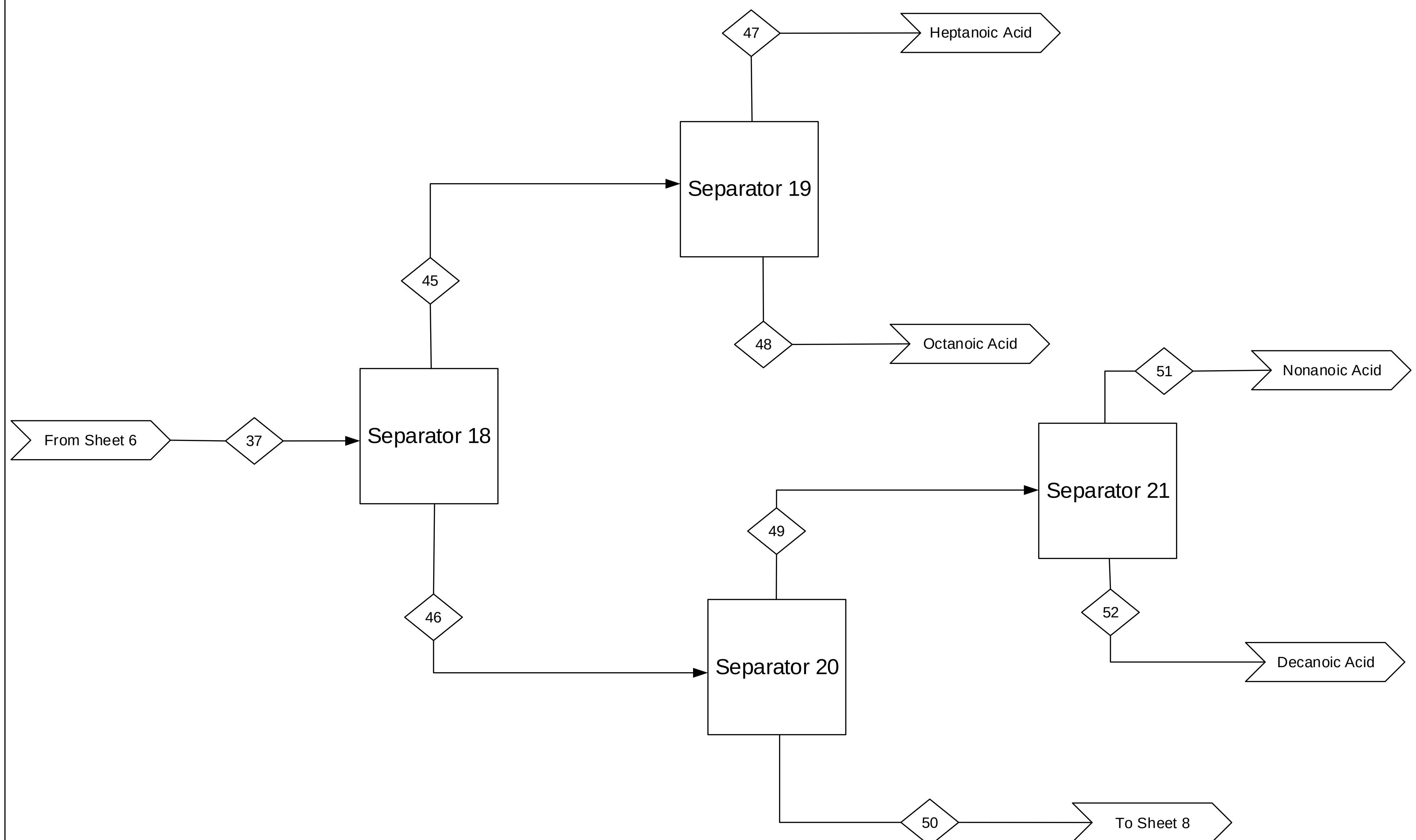
Drawing Type

Quantitative BFD

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 02-15-17	00-A-011/6	0



Component/Stream (kg/min)	37	45	46	47	48	49	50	51	52
Fatty Acids C7-C17	120	0	0	0	0	0	0	0	0
Fatty Acids C7-C8	0	26	0	0	0	0	0	0	0
Heptanoic Acid	0	0	0	15	0	0	0	0	0
Octanoic Acid	0	0	0	0	11	0	0	0	0
Fatty Acids C9-C17	0	0	91	0	0	0	0	0	0
Fatty Acids C9-C10	0	0	0	0	0	24	0	0	0
Nonanoic Acid	0	0	0	0	0	0	0	12	0
Decanoic Acid	0	0	0	0	0	0	0	0	11
Fatty Acids C11-C17	0	0	0	0	0	0	68	0	0
Total	120	26	91	15	11	24	68	12	11

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Separator 18: Separate C7-C8 fatty acids from C9-C18 fatty acids

Separator 19: Separate heptanoic acid byproduct from octanoic acid byproduct

Separator 20: Separate C9-C10 fatty acids from C11 and heavier fatty acids

Separator 21: Separate nonanoic acid byproduct from decanoic acid byproduct

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-010

Process Flow Diagram
00-A-012

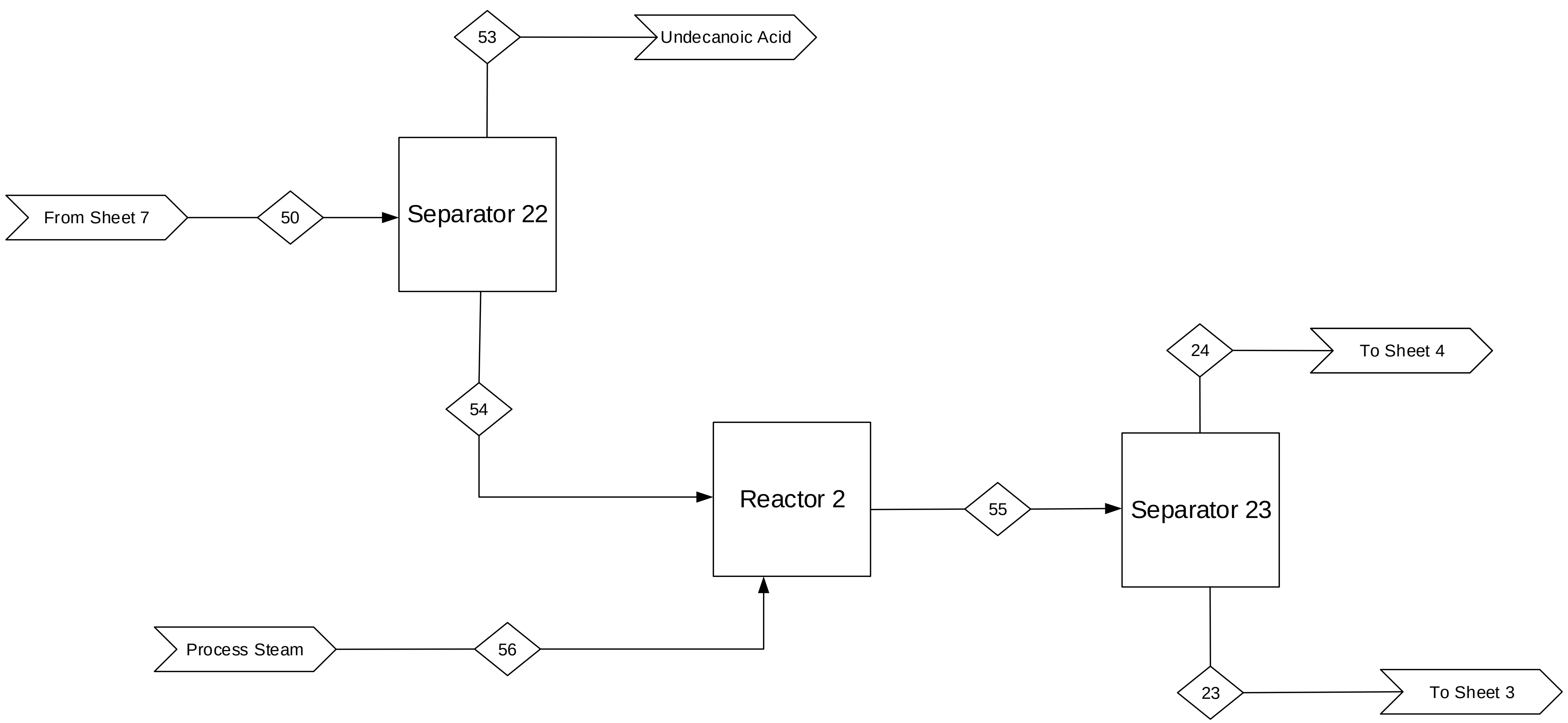
Drawing Type

Quantitative BFD

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 02-15-17	00-A-011/7	0



Component/Stream (kg/min)	23	24	50	53	54	55	56
C1-C17	0	0	0	0	0	64	0
C1-C10	0	14	0	0	0	0	0
C11-C17	50	0	0	0	0	0	0
Fatty Acids C11-C17	0	0	68	0	0	0	0
Fatty Acids C12-C17	0	0	0	0	64	0	0
Undecanoic Acid	0	0	0	5	0	0	0
Water	0	0	0	0	0	0	2
Total	50	14	68	5	64	64	2

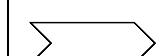
Notes

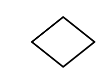
1. Drawing not to scale.
2. Mass balance may be off due to rounding.
3. Stream numbers do not correspond with PFD stream numbers.
4. Mass balances shown in kg/min.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Assume 100% separation in separators.
7. Reactor 2: React fatty acids and alkenes with steam to produce hydrocarbons

Separator 22: Separate undecanoic acid byproduct from C12-C18 fatty acids

Separator 23: Separate light ends from diesel fuel range intermediates

Special Symbols / Nomenclature


Input/Output


Stream Indicator

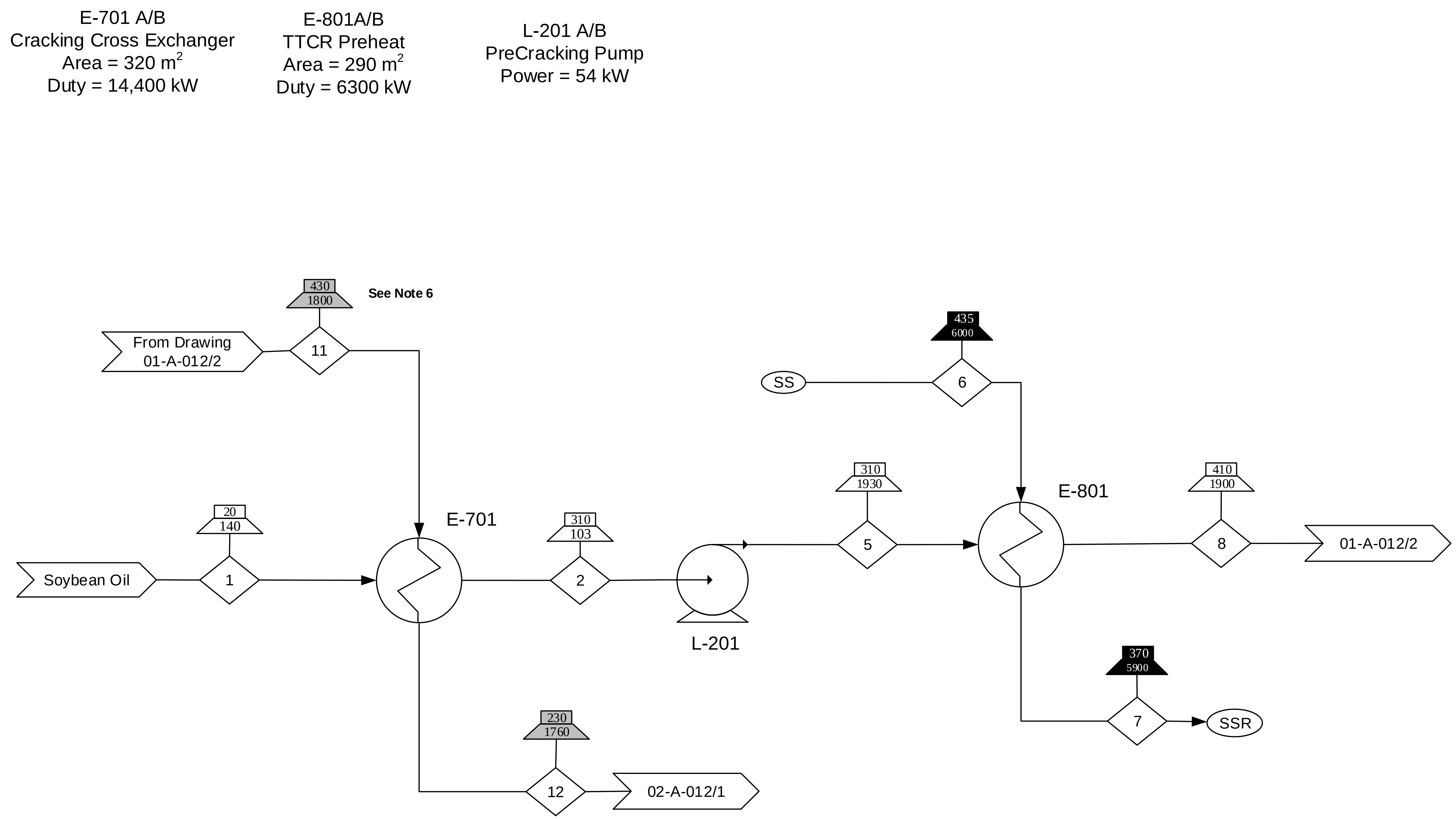
Reference Drawings:
Input/Output Diagram
00-A-010

Process Flow Diagram
00-A-012

Drawing Type
Quantitative BFD

Title
Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 02-15-17	00-A-011/8	0



Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 11 and 12 is an organic, aqueous, gaseous three phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase
SS Superheated Steam
SSR Superheated Steam Recycle

Reference Drawings:

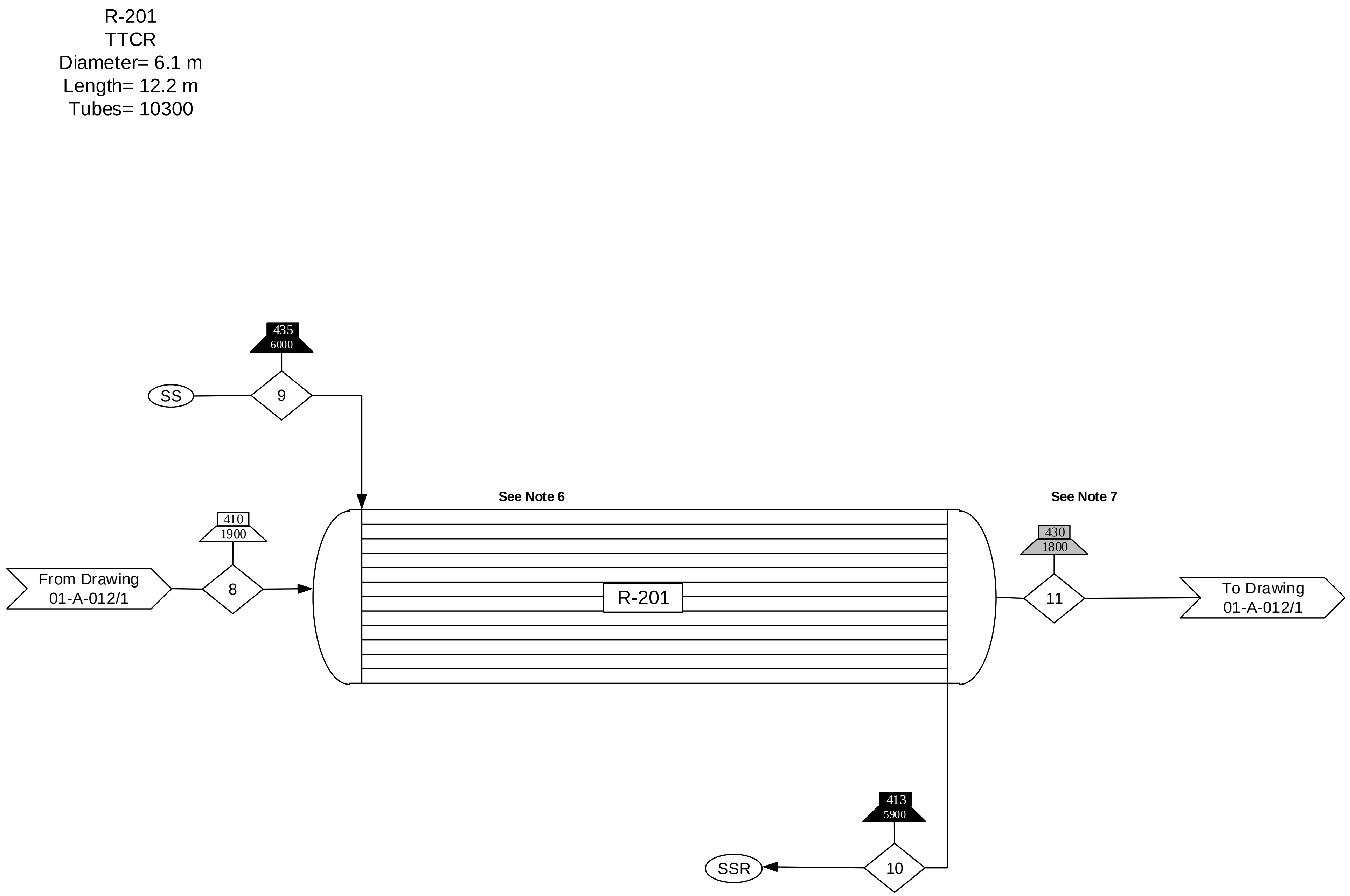
Input/Output Diagram
00-A-0010
Block Flow Diagram
00-A-011
Process Flow Diagrams
01-A-012

Component/Stream (kg/min)	1	2	5	6	7	8	11	12
Soybean Oil	1000	1000	1000	0	0	1000	0	0
C1-C50	0	0	0	0	0	0	1000	1000
Water	0	0	0	2400	2400	0	0	0
Total	1000	1000	1000	2400	2400	1000	1000	1000

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design- Thermal Cracking Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-25-17	01-A-012/1	0



Component/Stream (kg/min)	8	9	10	11
Soybean Oil	1000	0	0	0
C1-C50	0	0	0	1000
Water	0	8200	8200	0
Total	1000	8200	8200	1000

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. R-101 has a residence time of 1.17 hr.
7. Stream 11 is composed of a gas phase stream with entrained liquid tars.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase
SS Superheated Steam
SR Superheated Steam Recycle

Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
01-A-012
02-A-012

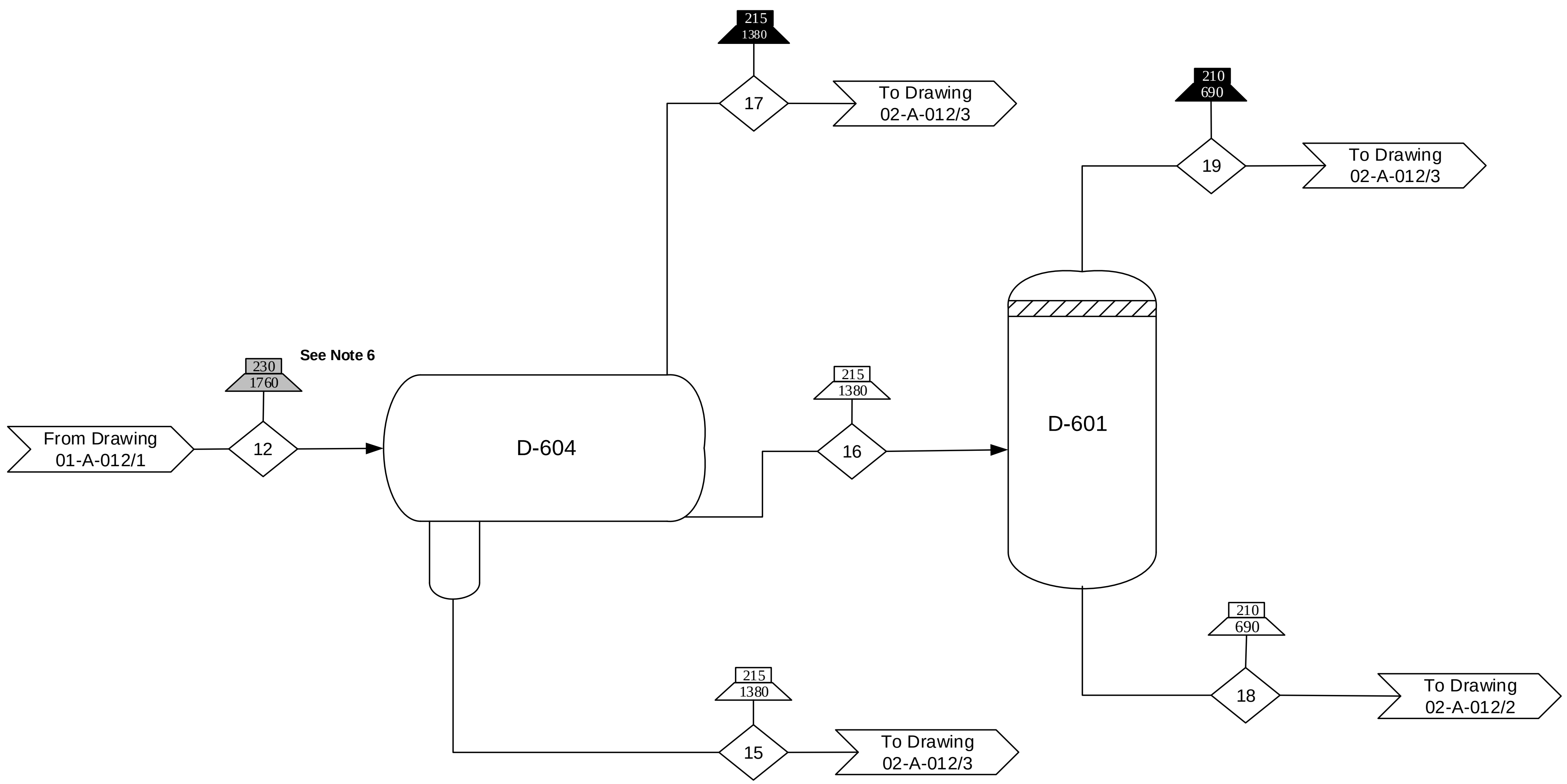
Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design- Thermal Cracking Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-25-17	01-A-012/2	0

D-601
Flash 1
Height= 5.8 m
Diameter= 1.4 m

D-604
Acetic Acid Separator 1
Length= 1.8 m
Diameter= 0.5 m

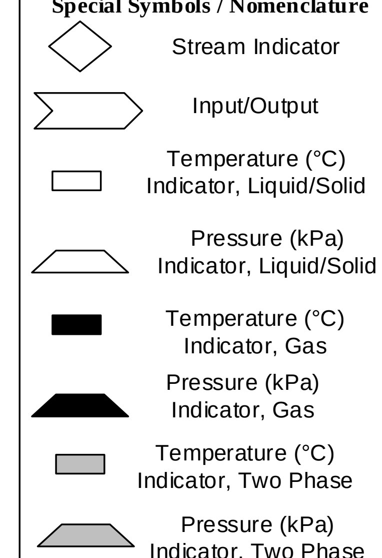


Component/Stream (kg/min)	12	15	16	17	18	19
C1-C50	1000	0	0	0	0	0
C1-C8	0	0	0	210	0	9
C4-C50	0	0	790	0	780	0
Acetic Acid	Trace	3	0	Trace	0	0
Propionic Acid	Trace	1	0	0	0	0
Total	1000	4	770	210	780	9

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 12 is composed of an aqueous and organic three phase stream.

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
01-A-012
02-A-012

Drawing Type
Process Flow Diagram

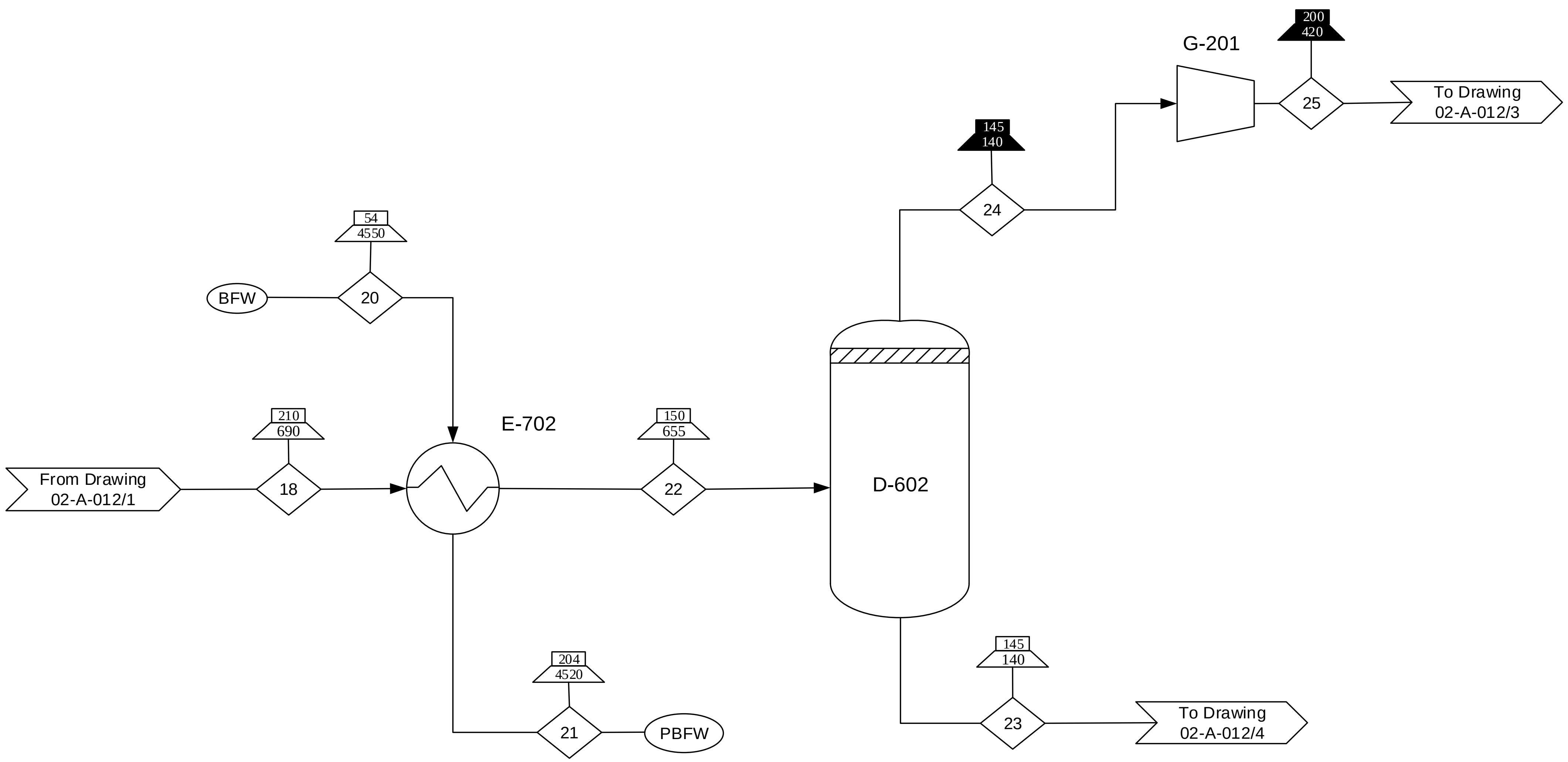
Title
Biorefinery Fatty Acid Recovery Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-25-17	02-A-012/1	0

D-602
Flash 2
Height= 5.8 m
Diameter= 1.4 m

E-702 A/B
Flash 2 Cooler
Area= 170 m^2
Duty= 2700 kW

G-201 A/B
Flash 2 Compressor
Power= 17 kW

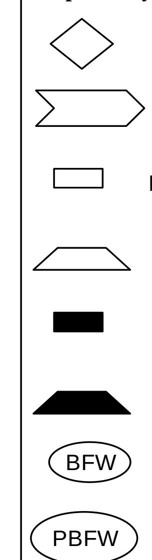


Component/Stream (kg/min)	18	20	21	22	23	24	25
C1-C8	0	0	0	0	0	9	9
C4-C50	780	0	0	780	770	0	0
Water	0	250	250	0	0	0	0
Total	780	250	250	780	770	9	9

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Boiler Feed Water
Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram 00-A-010
Block Flow Diagram 00-A-011
Process Flow Diagrams 02-A-012

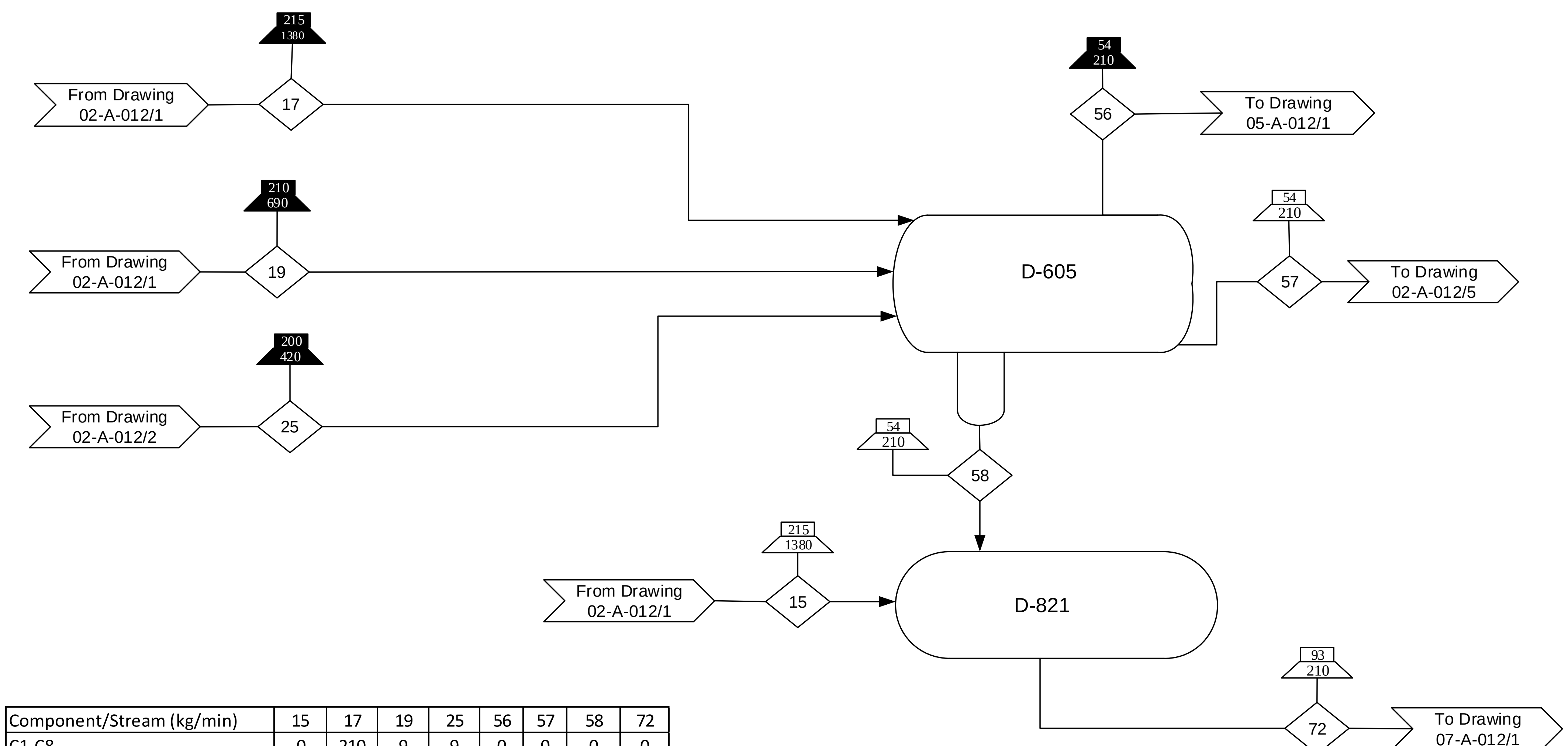
Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-25-17	02-A-012/2	0

D-605
Acetic Acid Separator 2
Height= 3.4 m
Diameter= 0.8 m

D-821
Acetic Acid Drum
Height= 1.2 m
Diameter= 0.3 m



Component/Stream (kg/min)	15	17	19	25	56	57	58	72
C1-C8	0	210	9	9	0	0	0	0
C1-C6	0	0	0	0	170	0	0	0
C6-C8	0	0	0	0	0	54	0	0
Water	0	0	0	0	0	0	0	0
Acetic Acid	3	0	0	0	0	0	1	4
Propionic Acid	1	0	0	0	0	0	Trace	1
Total	4	210	9	9	170	54	1	5

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase

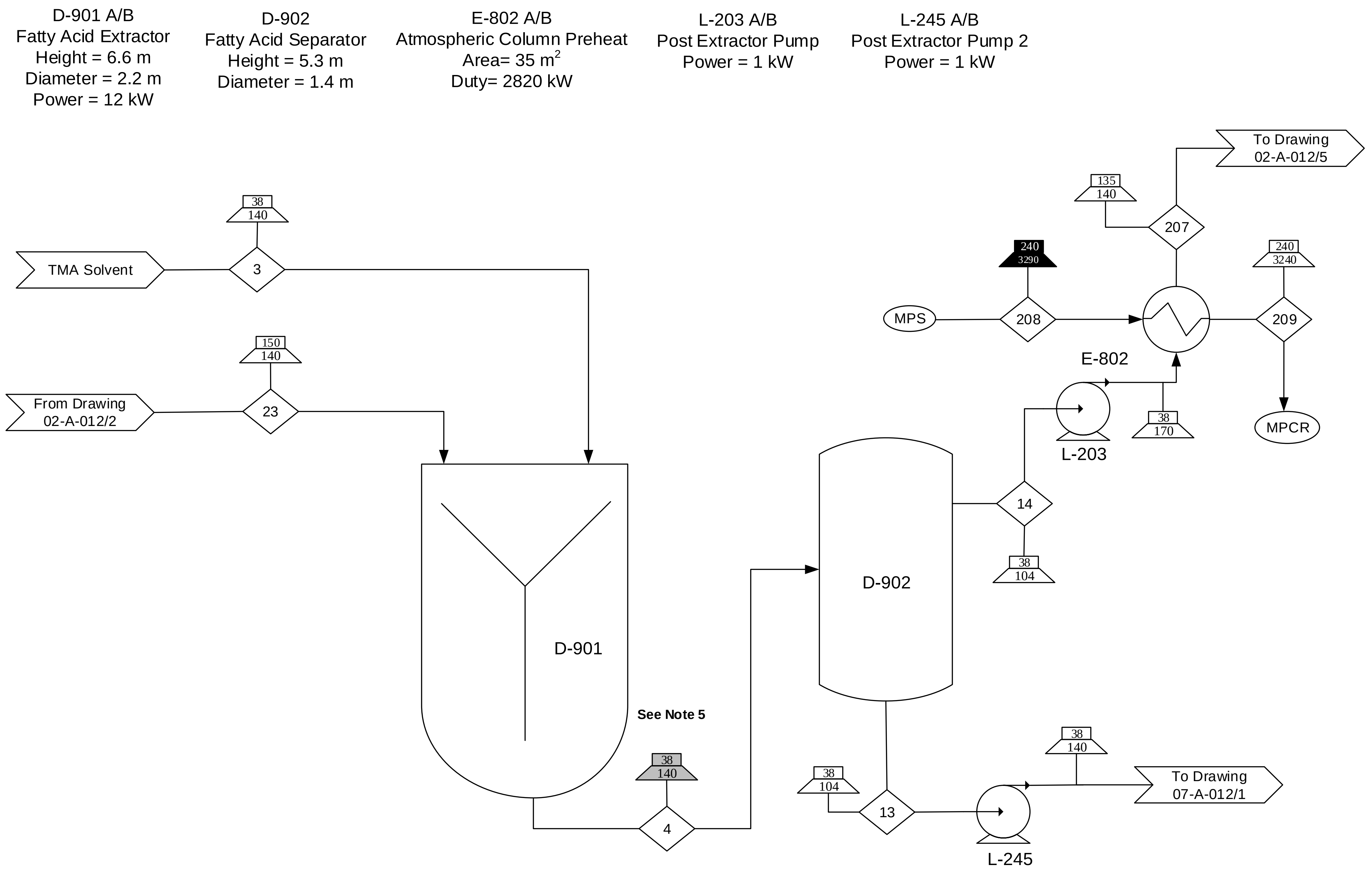
Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
02-A-012
05-A-012
07-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-25-17	02-A-012/3	0



Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
5. Stream 5 is a two phase stream composed of an aqueous and organic liquid.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
MPS Medium Pressure Steam
MPCR Medium Pressure Condensate Recycle

Reference Drawings:

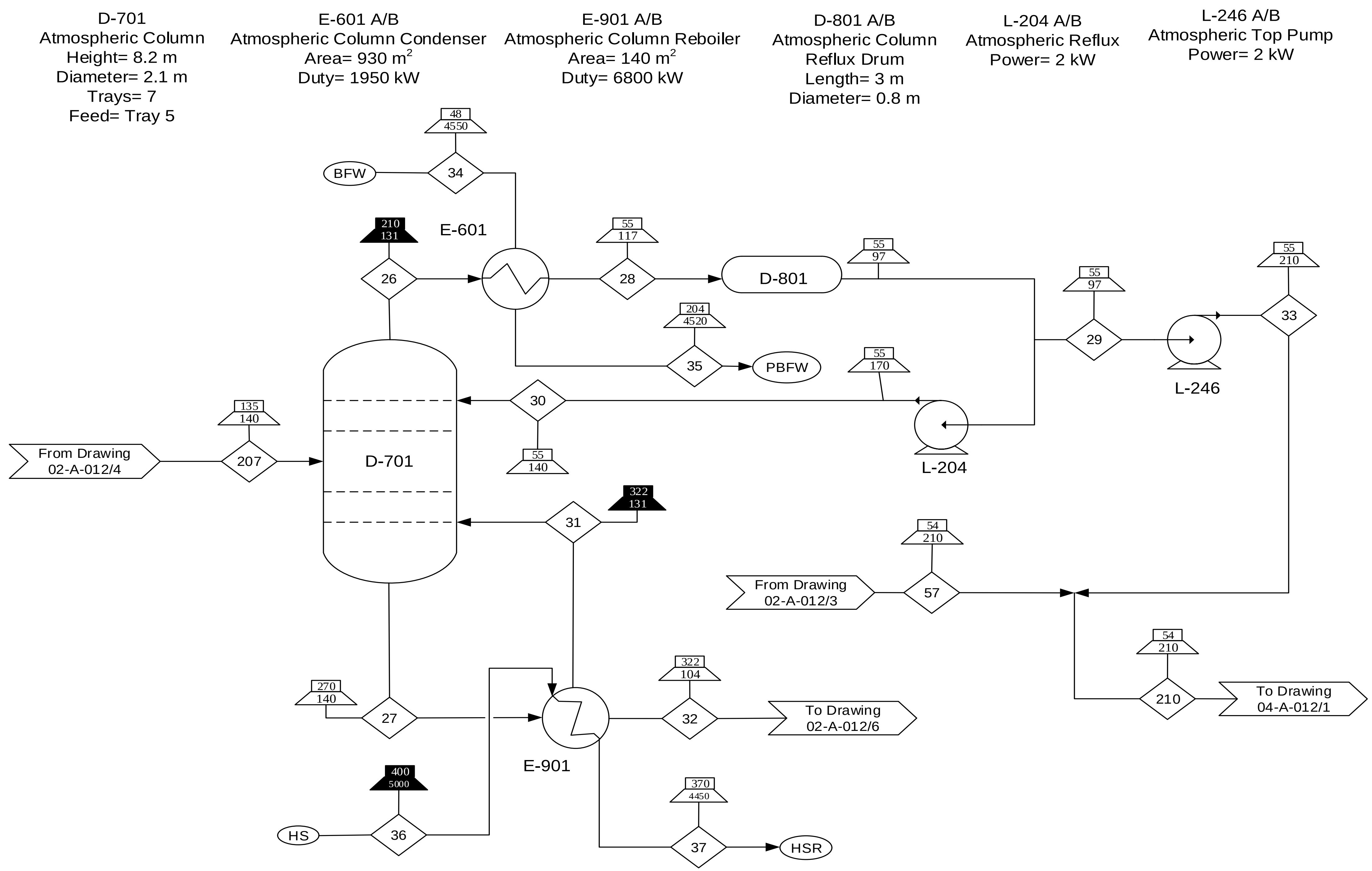
Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
02-A-012
07-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-25-17	02-A-012/4	0

Component/Stream (kg/min)	3	4	13	14	23	207	208	209
C4-C50	0	0	0	0	770	640	0	0
TMA	150	150	150	0	0	0	0	0
Water	640	640	640	0	0	0	95	95
Fatty Acids C3-C18	0	140	140	0	0	0	0	0
Organic C4-C50	0	640	0	640	0	0	0	0
Total	770	1540	910	640	770	640	95	95



Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
HS High Pressure Steam
HSR High Pressure Steam Condensate
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

Reference Drawings:

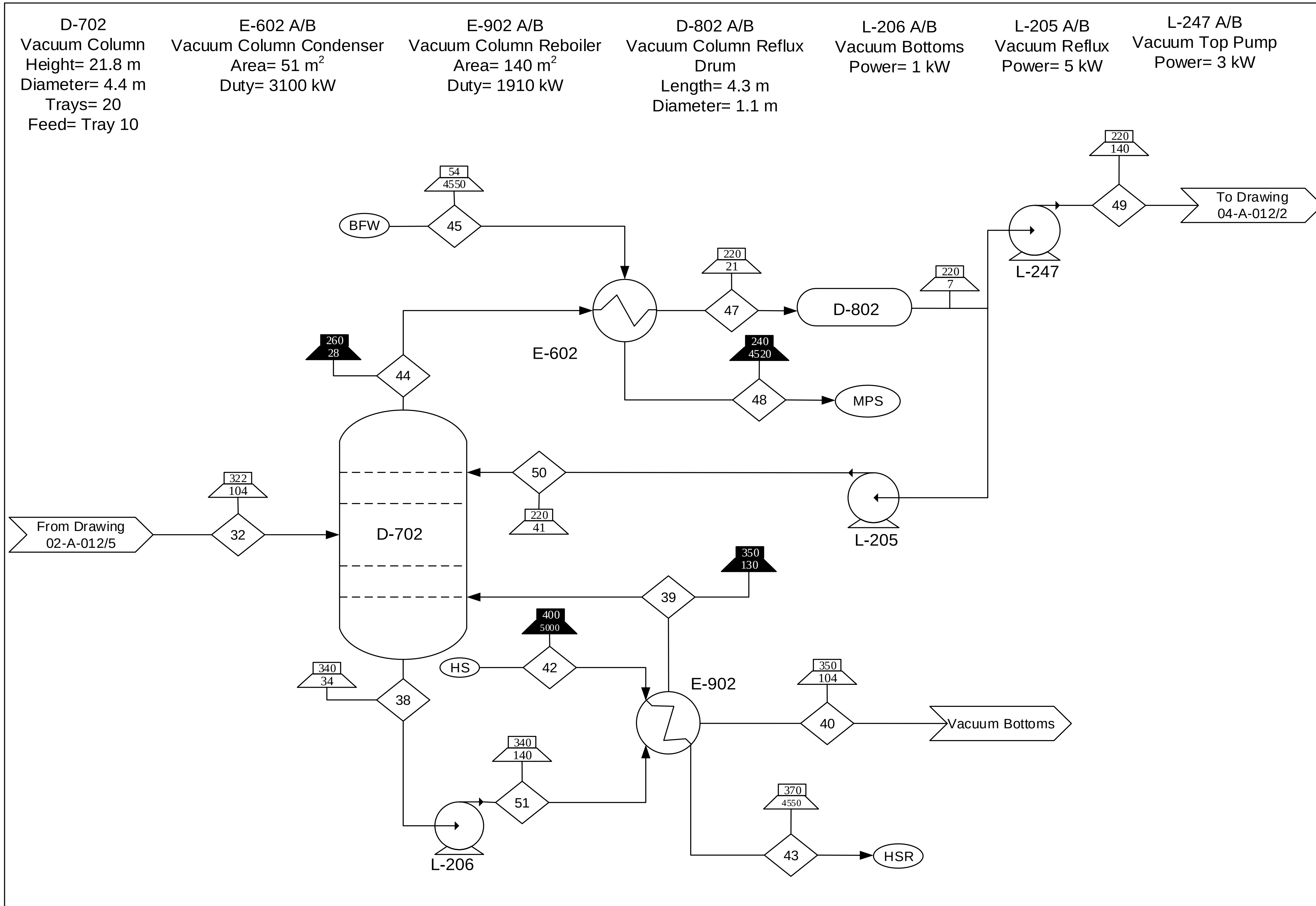
Input/Output Diagram 00-A-010
Block Flow Diagram 00-A-011
Process Flow Diagrams 02-A-012, 04-A-012

Component/Stream (kg/min)	26	27	28	29	30	31	32	33	34	35	36	37	57	207	210
C4-C12	150	0	150	140	9	0	0	140	0	0	0	0	54	0	190
C4-C50	0	1200	0	0	0	680	0	0	0	0	0	0	0	640	0
C13-C50	0	0	0	0	0	0	500	0	0	0	0	0	0	0	0
Water	0	0	0	0	0	0	0	0	180	180	2300	2300	0	0	0
Total	150	1200	150	140	9	680	500	140	180	180	2300	2300	54	640	190

Drawing Type: Process Flow Diagram

Title: Biorefinery Fatty Acid Recovery Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	02-A-012/5	0

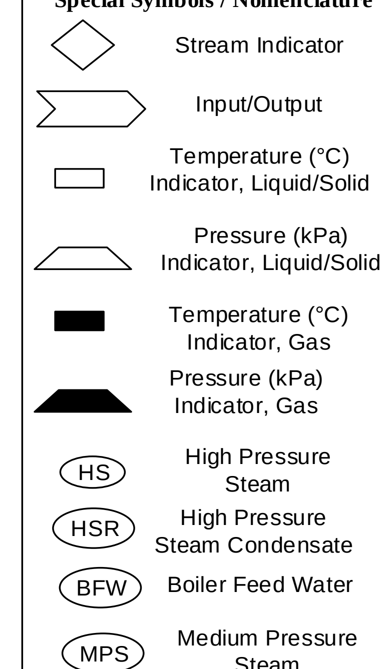


Component/Stream (kg/min)	32	38	39	40	42	43	44	45	47	48	49	50	51
C12-C50	500	0	0	0	0	0	0	0	0	0	0	0	0
C12-C30	0	0	0	0	0	0	410	0	410	0	250	160	0
C30-C50	0	590	320	250	0	0	0	0	0	0	0	0	590
Water	0	0	0	0	640	640	0	73	0	73	0	0	0
Total	500	590	320	250	640	640	410	73	410	73	250	160	590

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
02-A-012
04-A-012

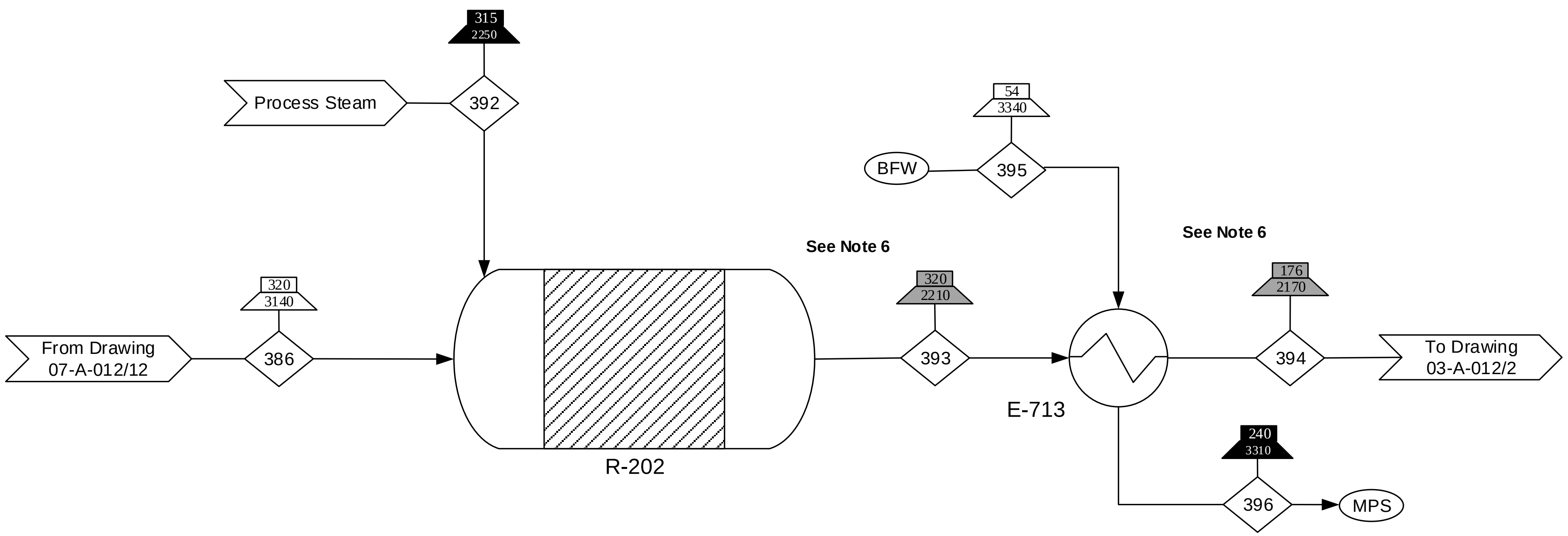
Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	02-A-012/6	0

R-202 A/B
Fatty Acid Decarboxylation Reactor
Diameter= 1.8 m
Length= 11.2 m
Catalyst= 62 m^3

E-713 A/B
Flash 4 Cooler
Area= 7 m^2
Duty= 560 kW

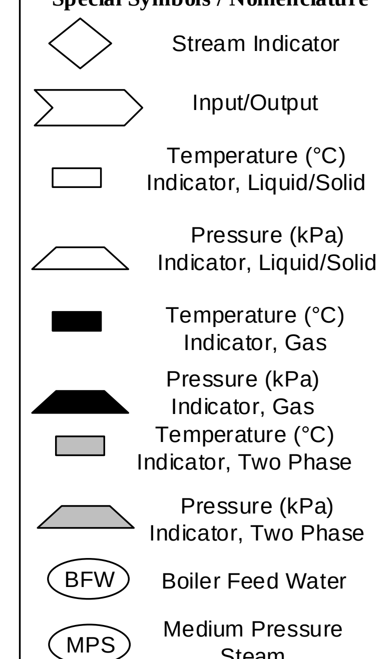


Component/Stream (kg/min)	386	392	393	394	395	396
Fatty Acids C12-C18	64	0	0	0	0	0
C1-C17	0	0	66	66	0	0
Water	0	2	0	0	14	14
Total	64	2	66	66	14	14

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 393 and 394 are two phase streams composed of gas and liquids.

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
03-A-012
07-A-012

Drawing Type
Process Flow Diagram

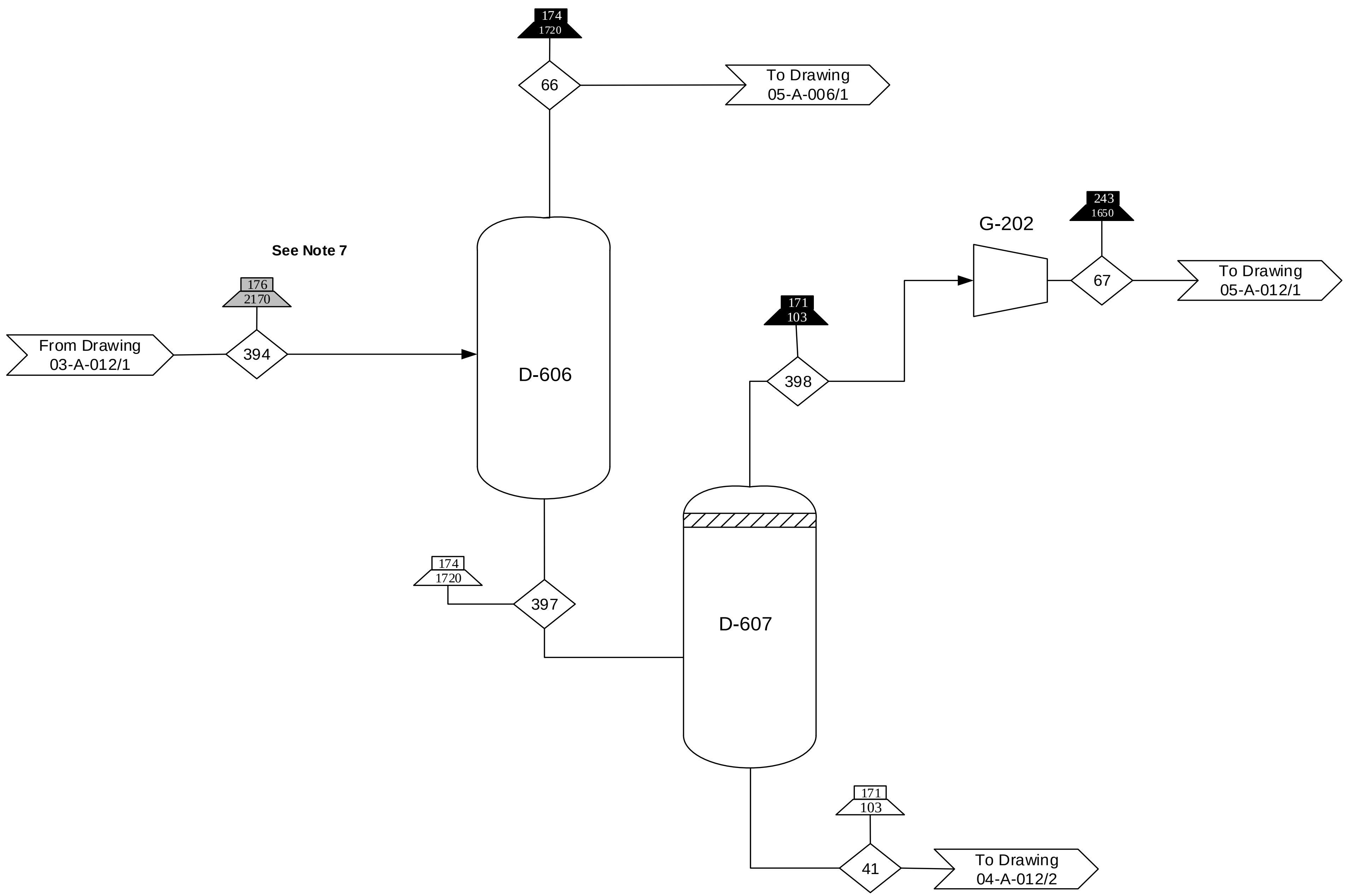
Title
Biorefinery Fatty Acid Recovery Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	03-A-012/1	0

D-606
Flash 4
Height= 2.8 m
Diameter= 0.8 m

D-607
Flash 5
Height= 2.8 m
Diameter= 0.8 m

G-202 A/B
Flash 3 Compressor
Power= 1 kW



Component/Stream (kg/min)	394	66	397	398	67	41
C1-C17	64	0	50	0	0	0
C1-C7	0	14	0	1	1	0
C8-C17	0	0	0	0	0	50
Total	64	14	50	1	1	50

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
7. Stream 394 is composed of a liquid and gas two phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase

Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
04-A-012
05-A-012
07-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	03-A-012/2	0

D-715
Hexane Splitter
Height= 7.9 m
Diameter= 0.9 m
Trays= 8
Feed 1= Stage 4
Feed 2 = Stage 3

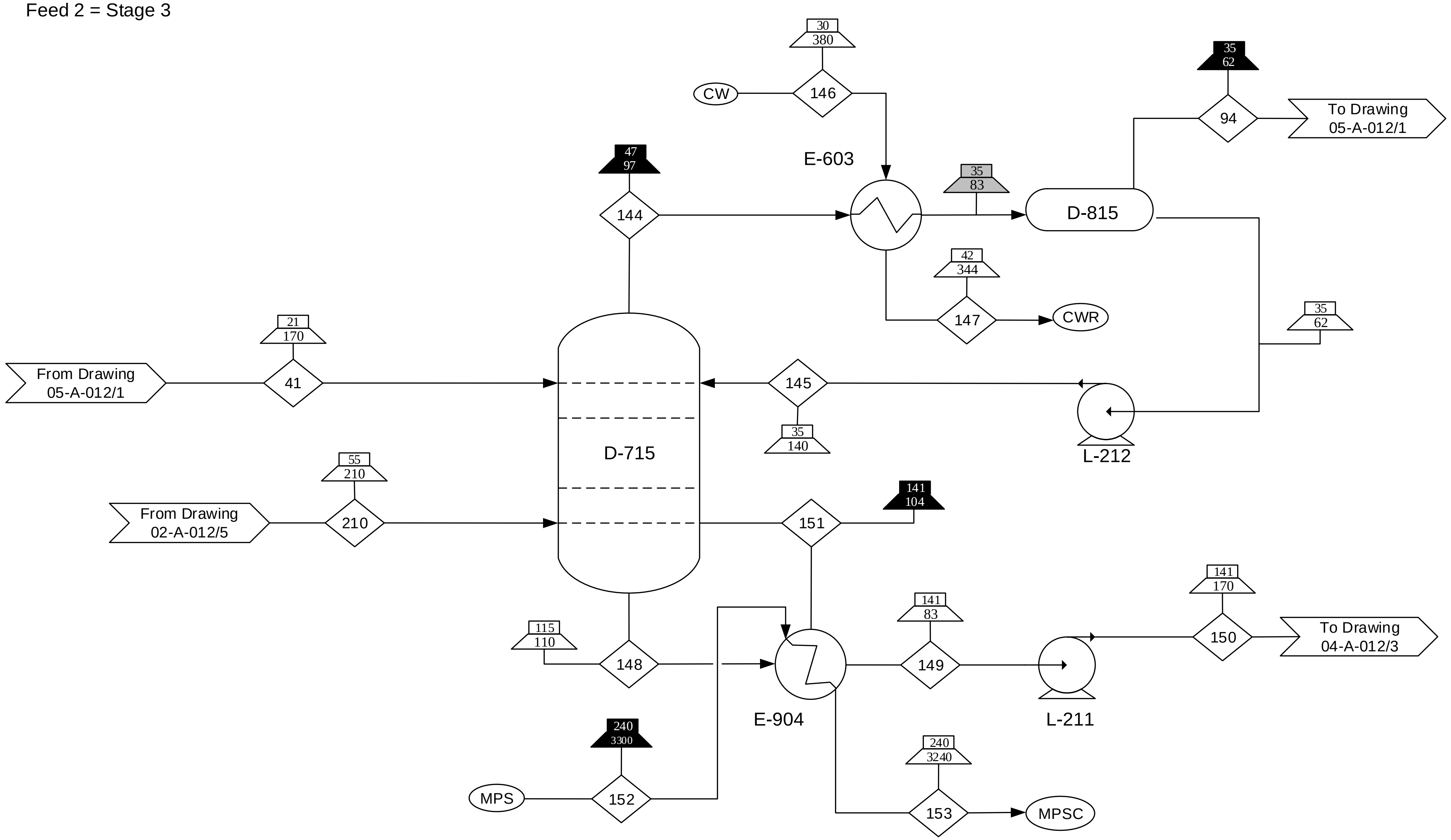
E-603 A/B
Hexane Splitter Condenser
Area= 100 m^2
Duty= 97 kW

E-904 A/B
Hexane Splitter Reboiler
Area= 24 m^2
Duty= 1100 kW

D-815 A/B
Hexane Splitter
Reflux Drum
Length= 1.8 m
Diameter= 0.5 m

L-211 A/B
Hexane Splitter Bottoms
Power= 1 kW

L-212 A/B
Hexane Splitter Reflux
Power= 2 kW



Notes
1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature
- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- Temperature (°C) Indicator, Two Phase
- Pressure (kPa) Indicator, Two Phase
- MPS: Medium Pressure Steam
- MPSC: Medium Pressure Steam Condensate
- CW: Cooling Water
- CWR: Cooling Water Recycle

Reference Drawings:
Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
02-A-012
04-A-012
05-A-012

Component/Stream (kg/min)	41	94	144	145	146	147	148	149	150	151	152	153	210
C1-C12	14	0	0	0	0	0	0	0	0	0	0	0	190
C1-C6	0	7	18	11	0	0	0	0	0	0	0	0	0
C5-C12	0	0	0	0	0	0	300	200	200	100	0	0	0
Water	0	0	0	0	91	91	0	0	0	0	36	36	0
Total	14	7	18	11	91	91	300	200	200	100	36	36	190

Drawing Type
Process Flow Diagram

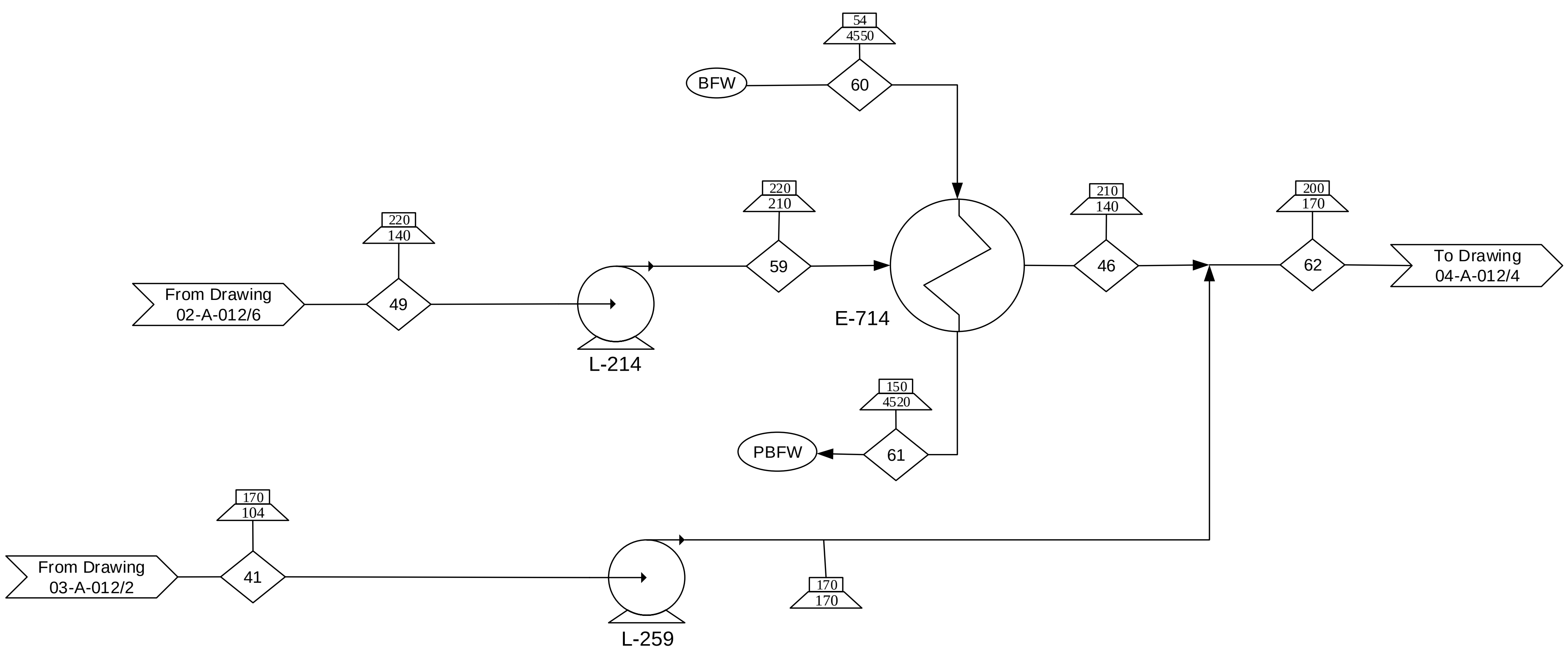
Title
Biorefinery Fatty Acid Recovery Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	04-A-012/1	0

E-714 A/B
Pre Jet Diesel Cut Cooler
Area= 3 m^2
Duty= 130 kW

L-214 A/B
Pre Jet Pump
Power = 2 kW

L-259 A/B
Pre Jet Pump 2
Power = 1 kW

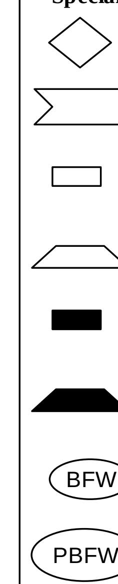


Component/Stream (kg/min)	49	41	46	59	60	61	62
C12-C30	250	0	250	250	0	0	0
C11-C17	0	50	0	0	0	0	0
C11-C30	0	0	0	0	0	0	300
Water	0	0	0	0	3	3	0
Total	250	50	250	250	3	3	300

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

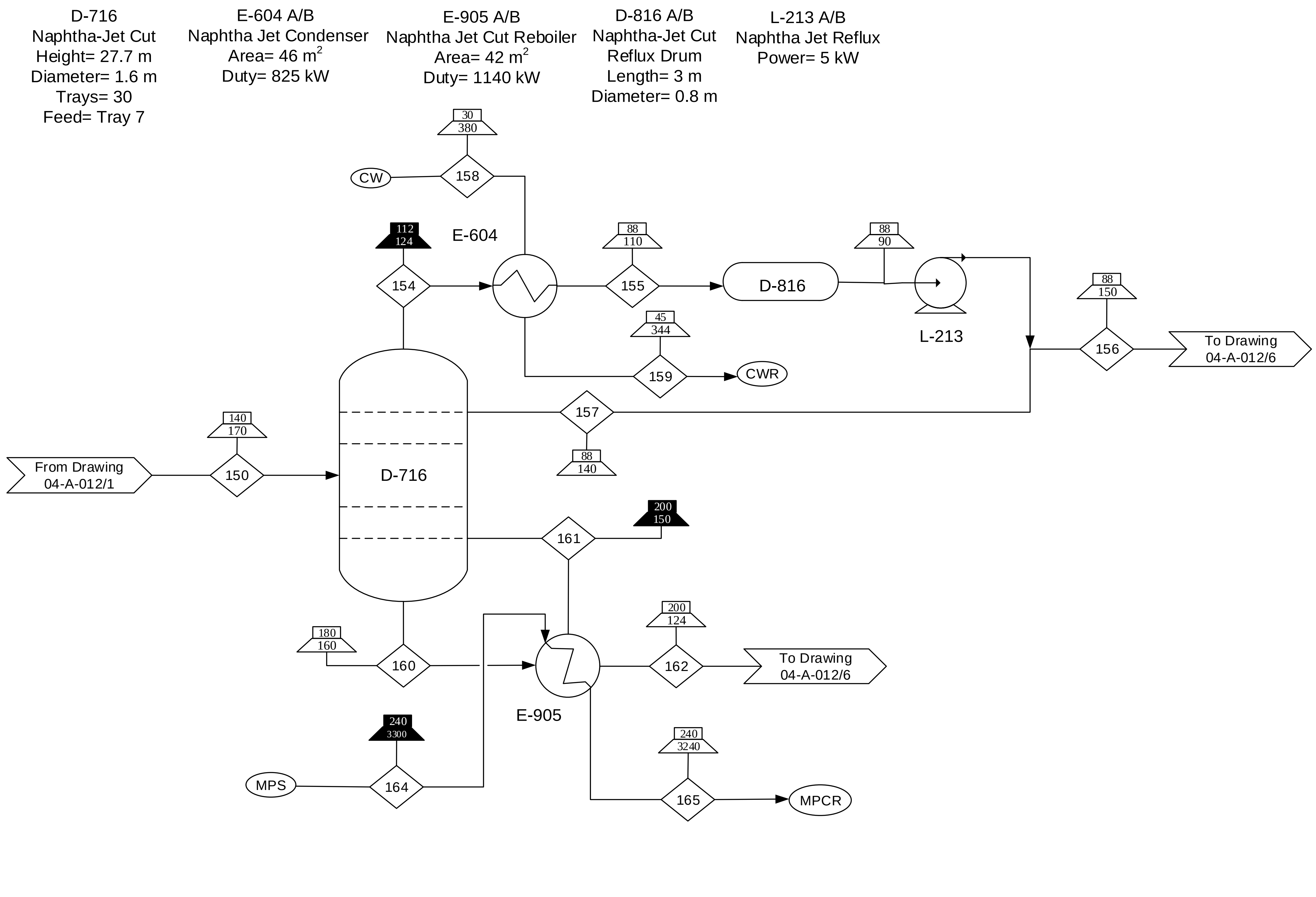
Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
02-A-012
03-A-012
04-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	04-A-012/2	0



Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
MPS Medium Pressure Steam
MPCR Medium Pressure Condensate Recycle
CW Cooling Water
CWR Cooling Water Recycle

Reference Drawings:

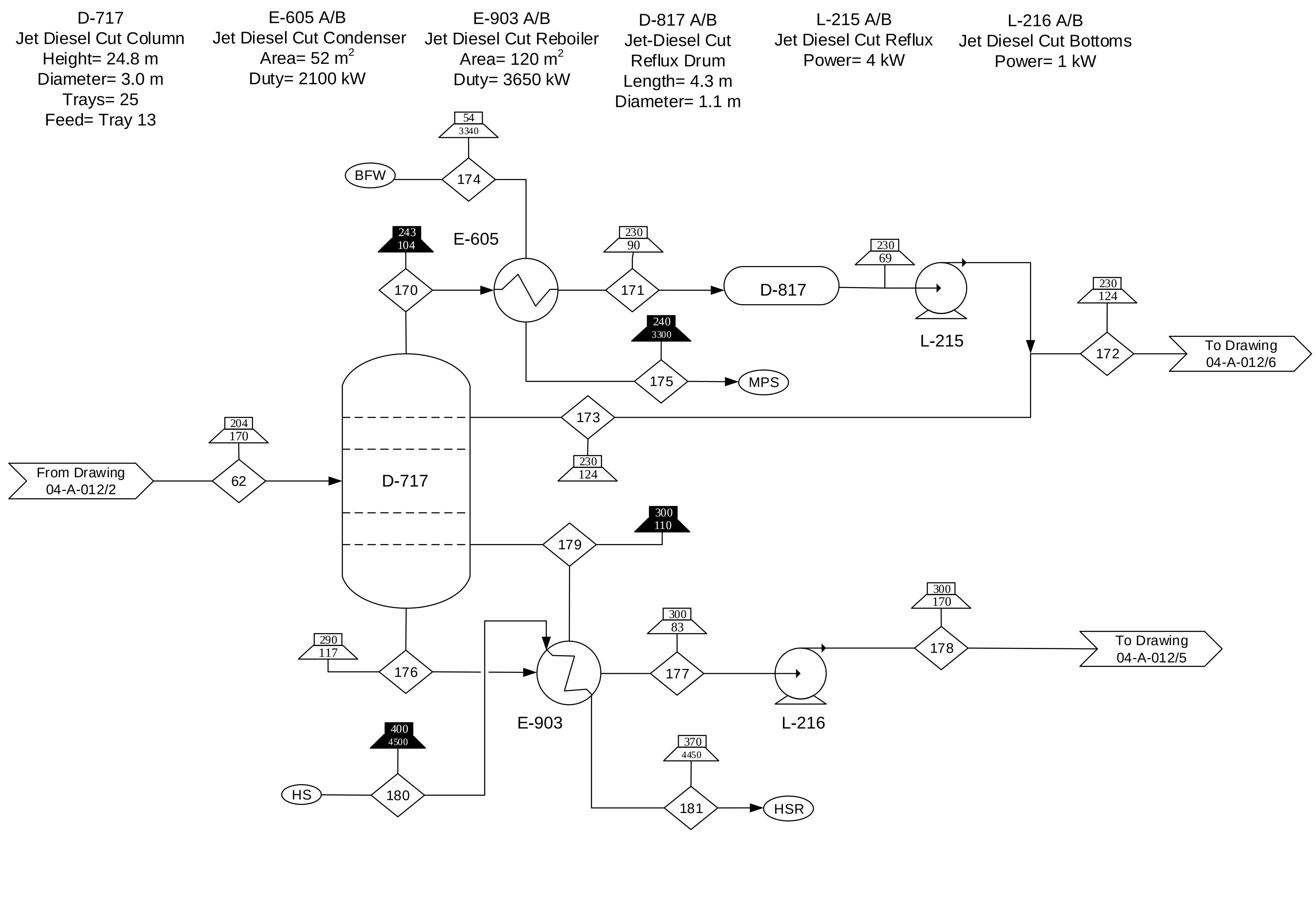
Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
04-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	04-A-012/3	0

Component/Stream (kg/min)	150	154	155	156	157	158	159	160	161	162	164	165
C5-C12	200	0	0	0	0	0	0	0	0	0	0	0
C7-C9	0	100	100	45	59	0	0	0	0	0	0	0
C9-C12	0	0	0	0	0	0	0	160	9	150	0	0
Water	0	0	0	0	0	770	770	0	0	0	39	39
Total	200	100	100	45	59	770	770	160	9	150	39	39



Component/Stream (kg/min)	62	170	171	172	173	174	175	176	177	178	179	180	181
C11-C30	300	0	0	0	0	0	0	0	0	0	0	0	0
C11-C30	0	340	340	64	280	0	0	0	0	0	0	0	0
C16-C30	0	0	0	0	0	0	0	680	240	240	440	0	0
Water	0	0	0	0	0	50	50	0	0	0	0	1300	1300
Total	300	340	340	64	280	50	50	680	240	240	440	1300	1300

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
HS High Pressure Steam
HSR High Pressure Steam Recycle
BFW Boiler Feed Water
MPS Medium Pressure Steam

Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
04-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	04-A-012/4	0

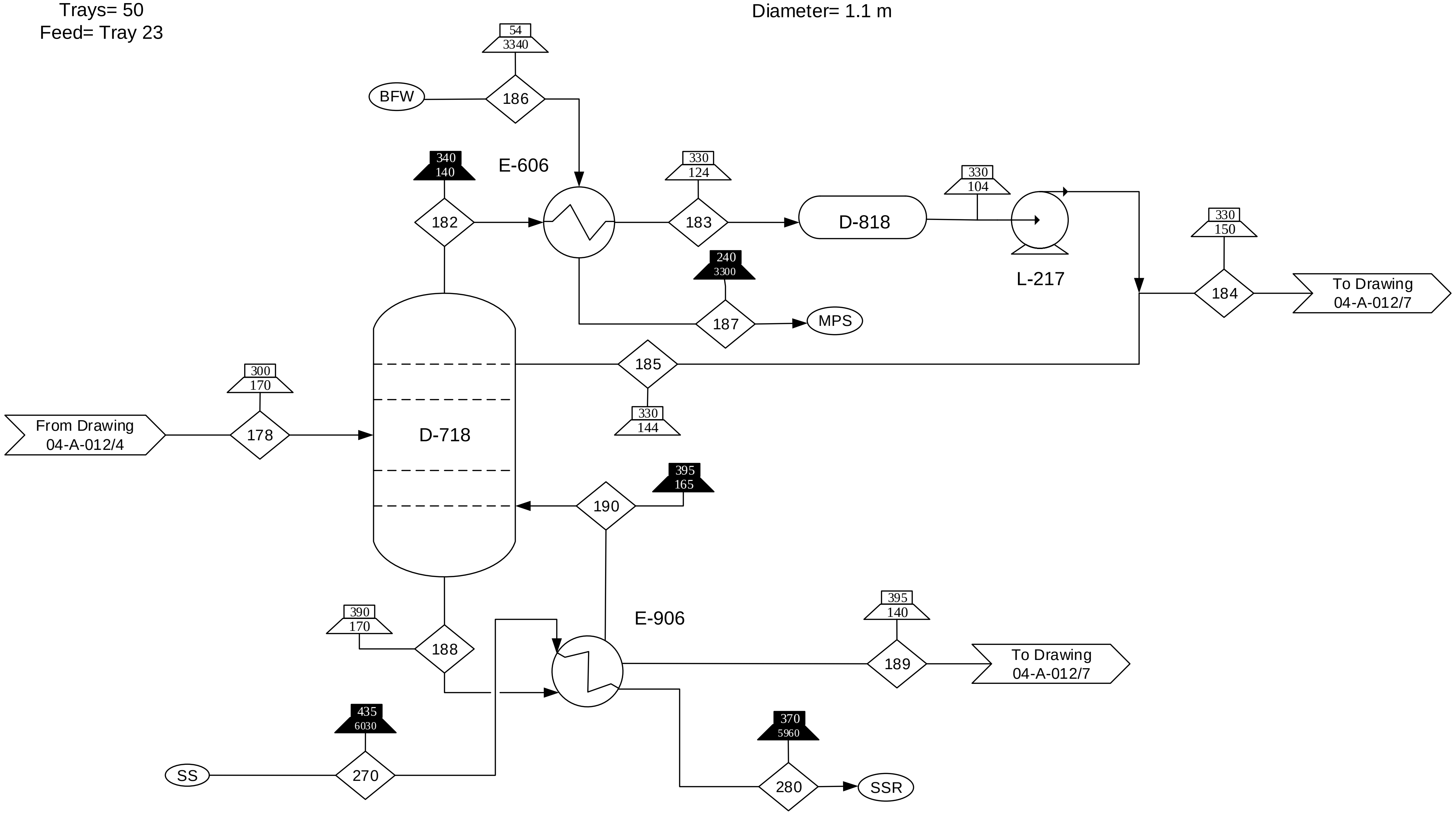
D-718
Diesel Fuel Oil Cut
Height= 47.9 m
Diameter= 4.3 m
Trays= 50
Feed= Tray 23

E-906 A/B
Diesel Fuel Oil Cut Reboiler
Area= 160 m^2
Duty= 2200 kW

E-606 A/B
Diesel Fuel Oil Cut Condenser
Area= 12 m^2
Duty= 1770 kW

D-818 A/B
Diesel Fuel Oil Cut
Reflux Drum
Length= 4.3 m
Diameter= 1.1 m

L-217 A/B
Diesel Fuel Oil Cut Reflux
Power= 8kW



Component/Stream (kg/min)	178	182	183	184	185	186	187	188	189	190	270	280
C16-C30	240	0	0	0	0	0	0	0	0	0	0	0
C16-C21	0	340	340	240	110	0	0	0	0	0	0	0
C22-C30	0	0	0	0	0	0	0	590	2	590	0	0
Water	0	0	0	0	0	43	43	0	0	0	2700	2700
Total	240	340	340	240	110	43	43	590	2	590	2700	2700

Notes

1. Drawing is not to scale.

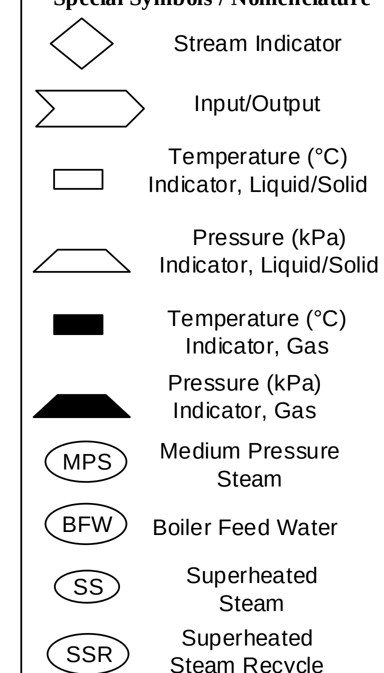
2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



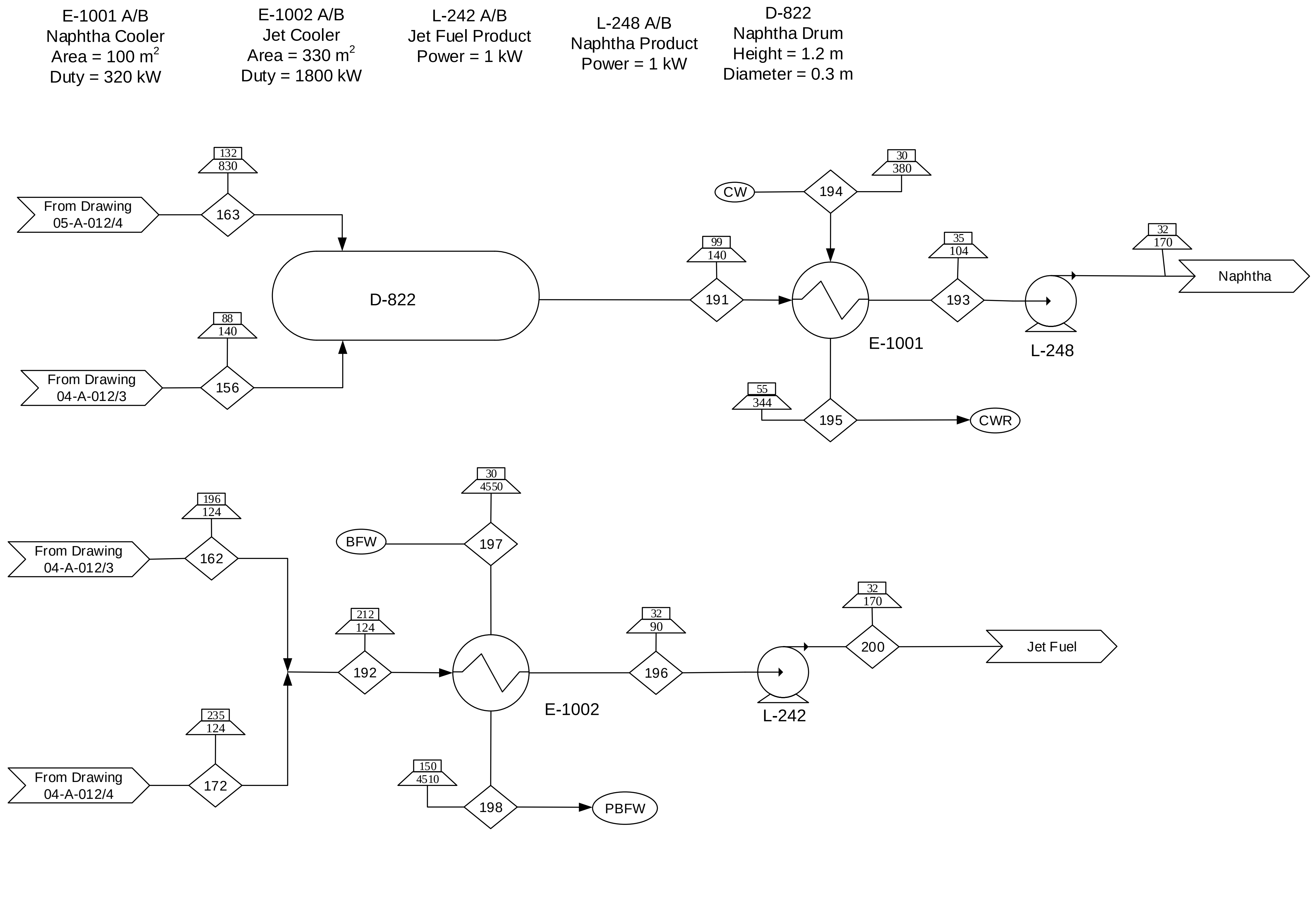
Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
04-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	04-A-012/5	0



Component/Stream (kg/min)	156	162	163	172	191	192	193	194	195	196	197	198	200
Naphtha Product	45	0	39	0	86	0	86	0	0	0	0	0	0
Jet Fuel Product	0	150	0	64	0	210	0	0	0	210	0	0	210
Water	0	0	0	0	0	0	0	300	300	0	1700	1700	0
Total	45	150	39	64	86	210	86	300	300	210	1700	1700	210

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°C) Indicator, Liquid/Solid

Pressure (kPa) Indicator, Liquid/Solid

Temperature (°C) Indicator, Gas

Pressure (kPa) Indicator, Gas

CW — Cooling Water

CWR — Cooling Water Recycle

BFW — Boiler Feed Water

PBFW — Preheated Boiler Feed Water

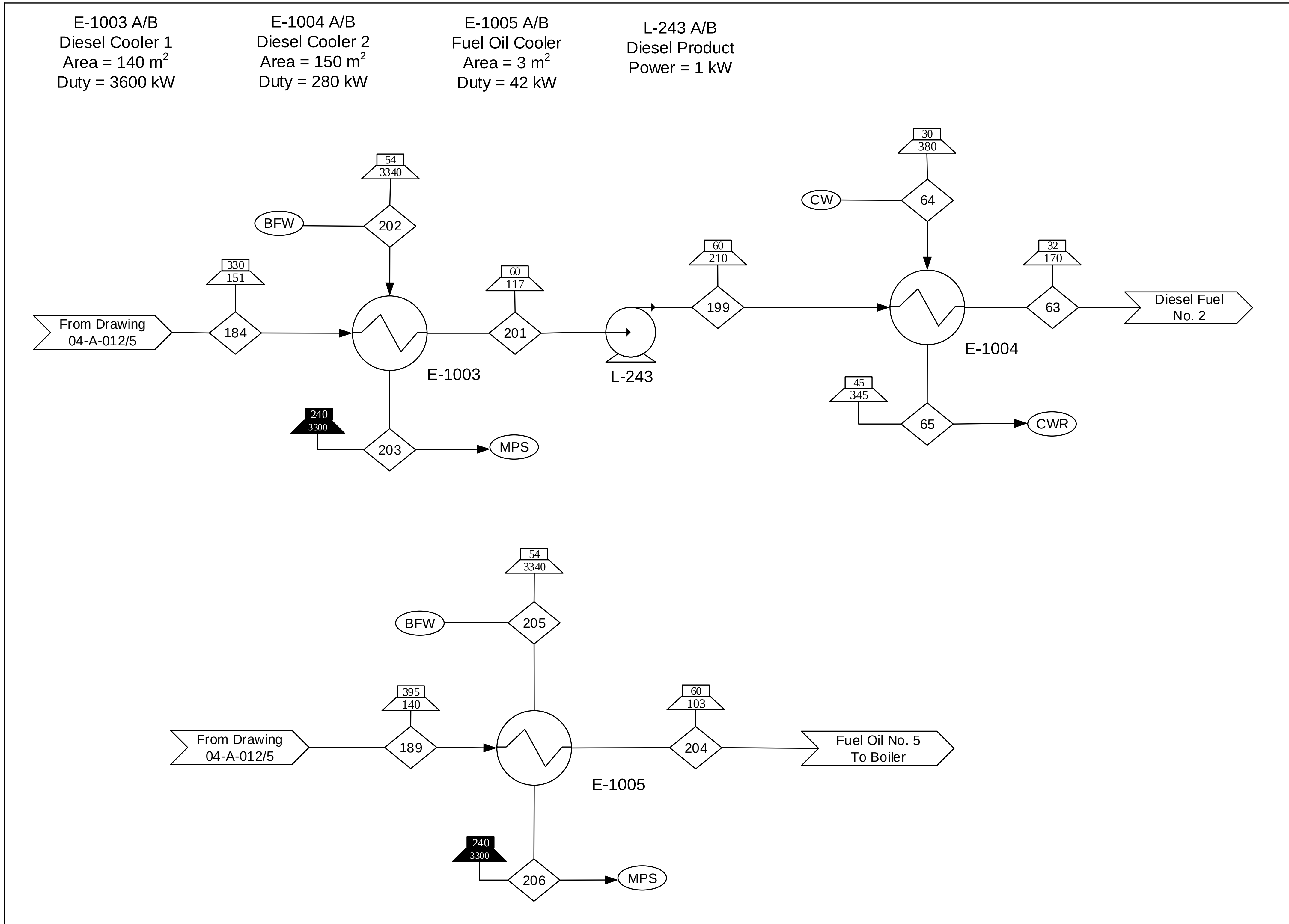
Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
04-A-012
05-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	04-A-012/6	0



Component/Stream (kg/min)	63	64	65	184	189	201	202	203	204	205	206	199
Diesel Fuel No. 2 Product	240	0	0	240	0	240	0	0	0	0	0	240
Fuel Oil No. 5 Product	0	0	0	0	2	0	0	0	2	0	0	0
Water	0	270	270	0	0	0	86	86	0	41	41	0
Total	240	270	270	240	2	240	86	86	2	41	41	240

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- MPS: Medium Pressure Steam
- BFW: Boiler Feed Water
- CW: Cooling Water
- CWR: Cooling Water Recycle

Reference Drawings:

Input/Output Diagram 00-A-010
Block Flow Diagram 00-A-011
Process Flow Diagrams 04-A-012, 05-A-012

Drawing Type
Process Flow Diagram

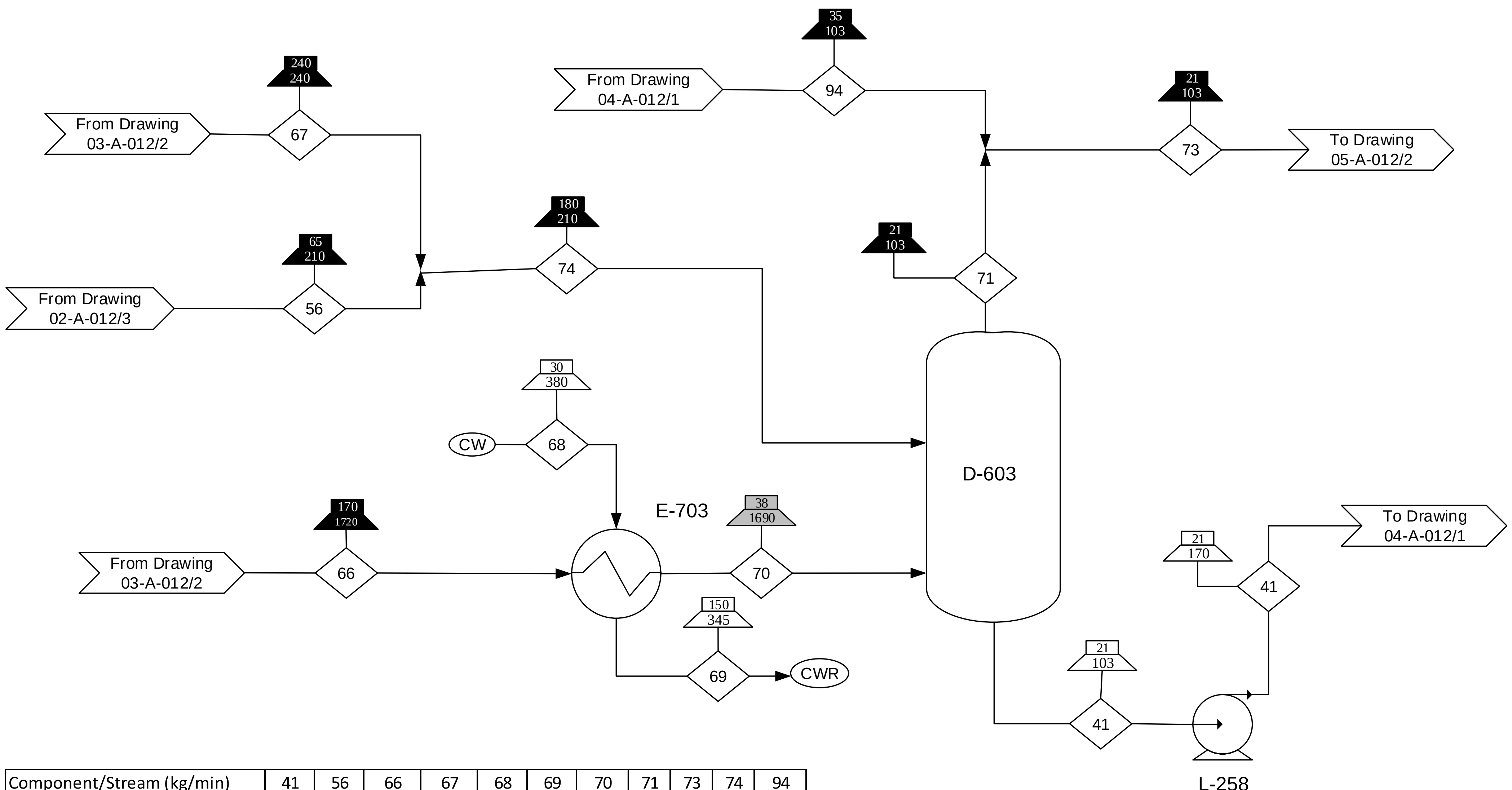
Title
Biorefinery Fatty Acid Recovery Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	04-A-012/7	0

D-603
Flash 3
Height= 2m
Diameter= 1.2 m

E-703 A/B
Pre-Flash 3 Cooler
Area= 60 m^2
Duty= 250 kW

L-258 A/B
Flash 3 Pump
Power= 1 kW

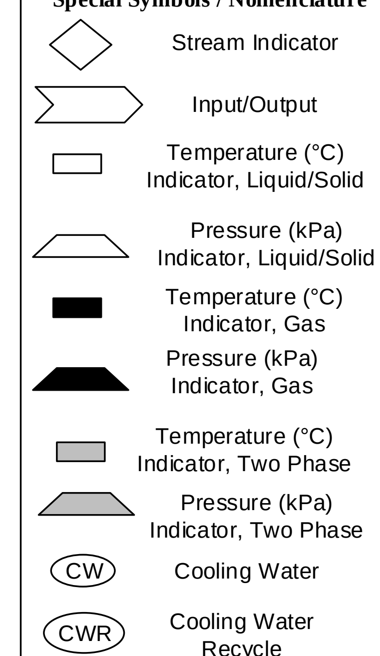


Component/Stream (kg/min)	41	56	66	67	68	69	70	71	73	74	94
C1-C5	0	0	0	0	0	0	0	170	180	0	7
C5-C7	14	0	0	0	0	0	0	0	0	0	0
C1-C7	0	170	14	1	0	0	14	0	0	170	0
C1-C6	0	0	0	0	0	0	0	0	0	0	0
C6-C7	0	0	0	0	0	0	0	0	0	0	0
Water	0	0	0	0	240	240	0	0	0	0	0
Total	14	170	14	1	240	240	14	170	180	170	7

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



Reference Drawings:

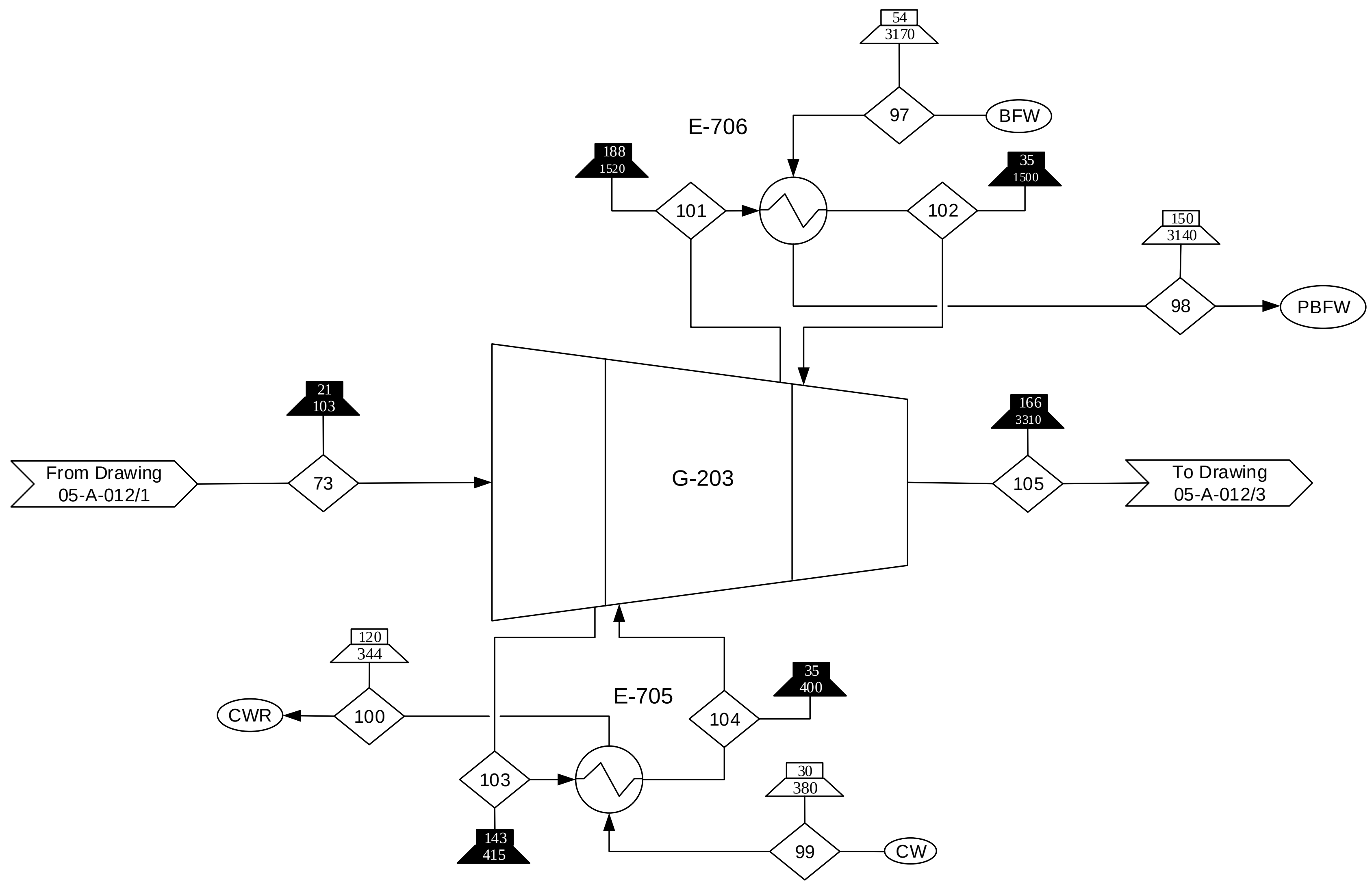
Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
02-A-012
03-A-012
04-A-012
05-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	05-A-012/1	0

G-203	E-705 A/B	E-706 A/B
Light End Compressor	Interstage Cooler 1	Interstage Cooler 2
3 Stages	Area= 37 m^2	Area= 40 m^2
Stage 1 Power= 500 kW	Duty= 530 kW	Duty= 640 kW
Stage 1 Power= 500 kW		
Stage 1 Power= 500 kW		



Component/Stream (kg/min)	73	97	98	99	100	101	102	103	104	105
C1-C5	180	0	0	0	0	180	180	180	180	180
Water	0	590	590	500	500	0	0	0	0	0
Total	180	590	590	500	500	180	180	180	180	180

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- CW — Cooling Water
- CWR — Cooling Water Recycle
- BFW — Boiler Feed Water
- PBFW — Preheated Boiler Feed Water

Reference Drawings:

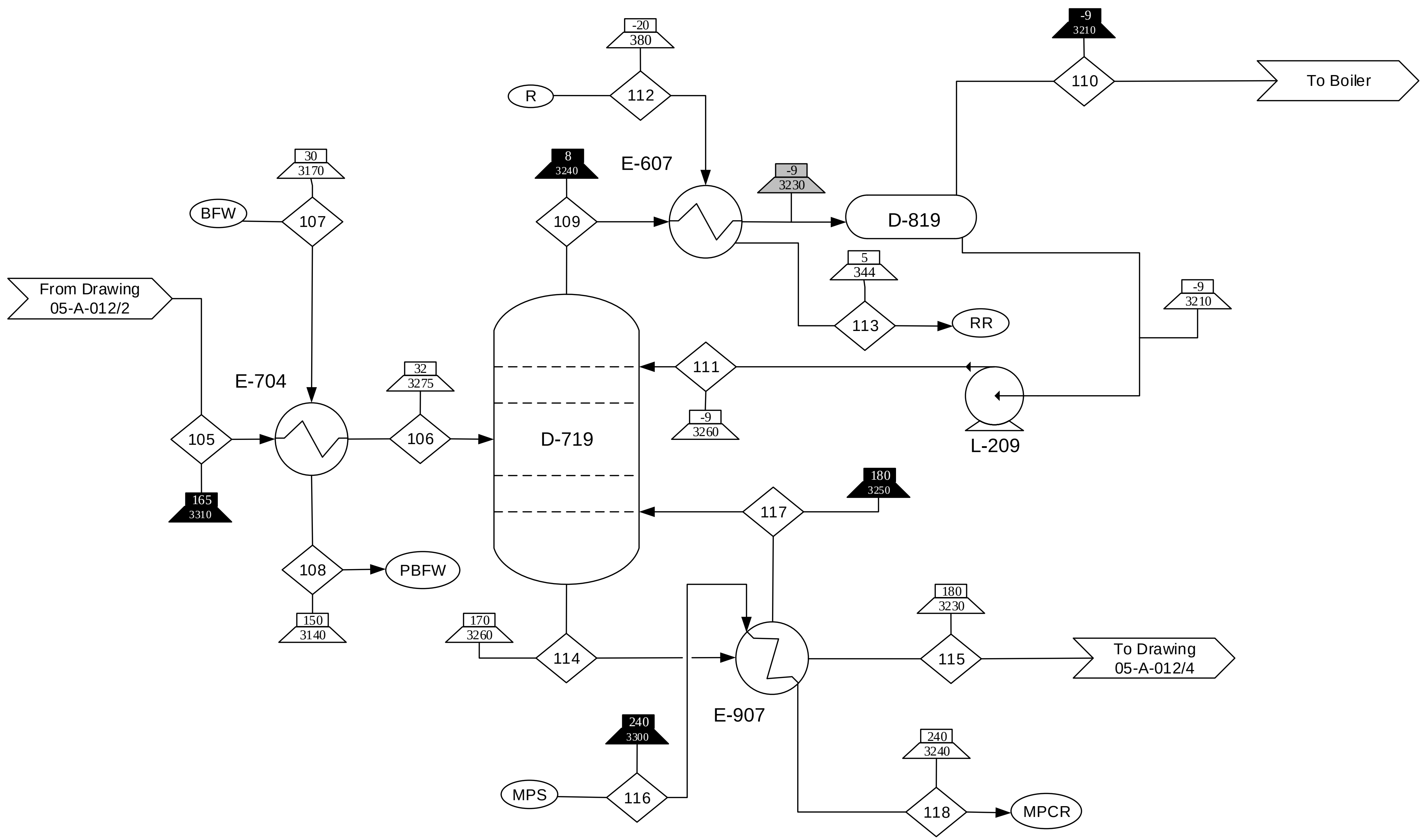
Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
05-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	05-A-012/2	0

D-719	E-704 A/B	E-607 A/B	E-907 A/B	D-819 A/B	L-209 A/B
Syngas Column	Syngas Cooler	Syngas Condenser	Syngas Reboiler	Syngas Column Reflux Drum	Syngas Column Reflux
Height= 37.1 m	Area= 810 m^2	Area= 230 m^2	Area= 14 m^2	Length= 3.6 m	Power= 5 kW
Diameter= 0.2 m	Duty= 2400 kW	Duty= 390 kW	Duty= 730 kW	Diameter= 0.9 m	
Trays= 40					
Feed= Tray 15					



Component/Stream (kg/min)	105	106	107	108	109	110	111	112	113	114	115	116	117	118
C1-C5	180	180	0	0	0	0	0	0	0	0	0	0	0	0
C1-C3	0	0	0	0	170	120	50	0	0	0	0	0	0	0
C4-C5	0	0	0	0	0	0	0	0	0	200	59	0	150	0
Water	0	0	2300	2300	0	0	0	360	360	0	0	25	0	25
Total	180	180	2300	2300	170	120	50	360	360	200	59	25	150	25

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- Temperature (°C) Indicator, Two Phase
- Pressure (kPa) Indicator, Two Phase
- MPS: Medium Pressure Steam
- MPCR: Medium Pressure Condensate Recycle
- R: Refrigerant
- RR: Refrigerant Return
- BFW: Boiler Feed Water
- PBFW: Preheated Boiler Feed Water

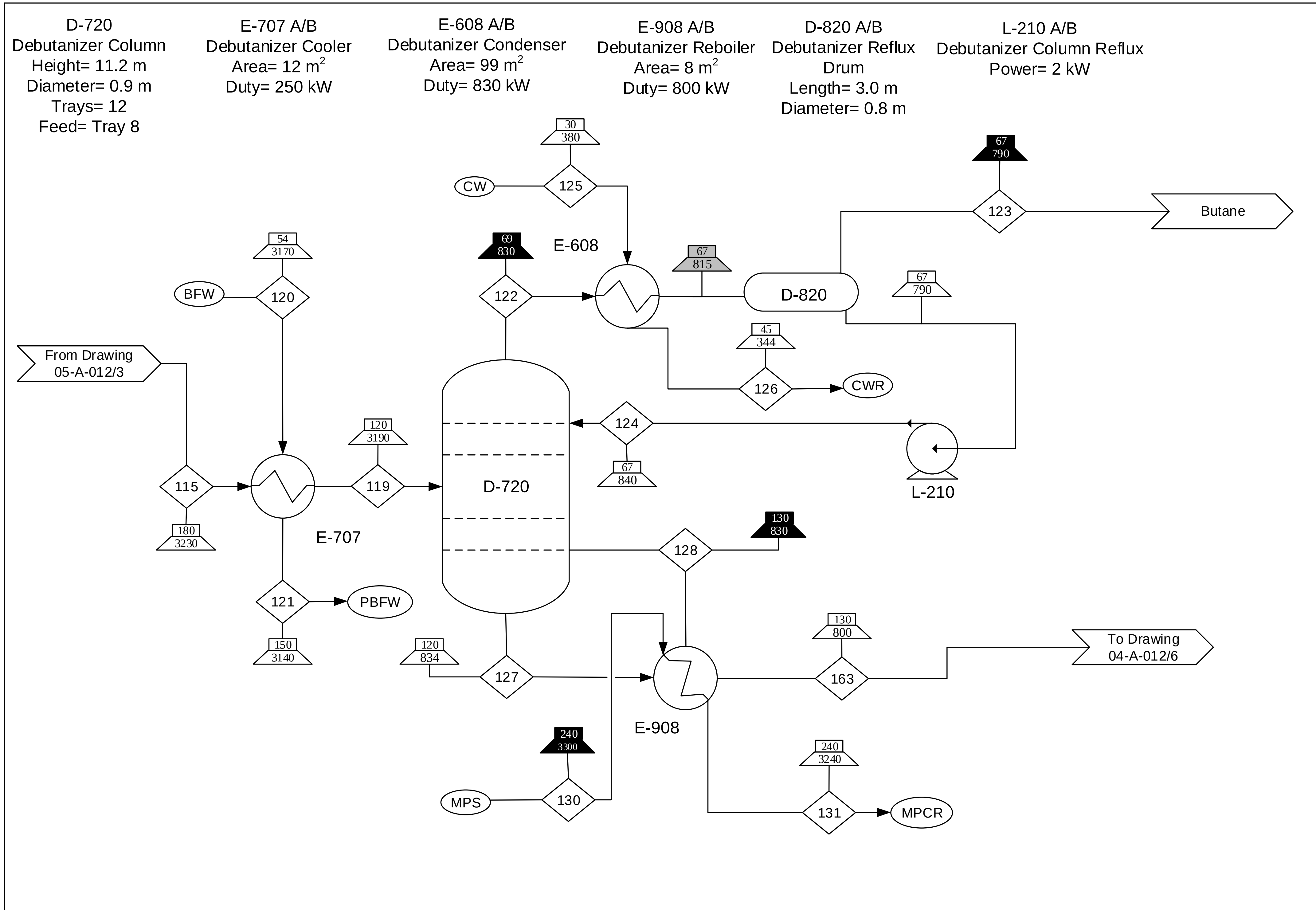
Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
05-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	05-A-012/3	0



Component/Stream (kg/min)	115	119	120	121	122	123	124	125	126	127	128	130	131	163
C4-C6	59	59	0	0	0	0	0	0	0	0	0	0	0	0
Butane	0	0	0	0	130	19	110	0	0	0	0	0	0	0
C5-C6	0	0	0	0	0	0	0	0	0	160	120	0	0	39
Water	0	0	240	240	0	0	0	820	820	0	0	27	27	0
Total	59	59	240	240	130	19	110	820	820	160	120	27	27	39

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
5. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

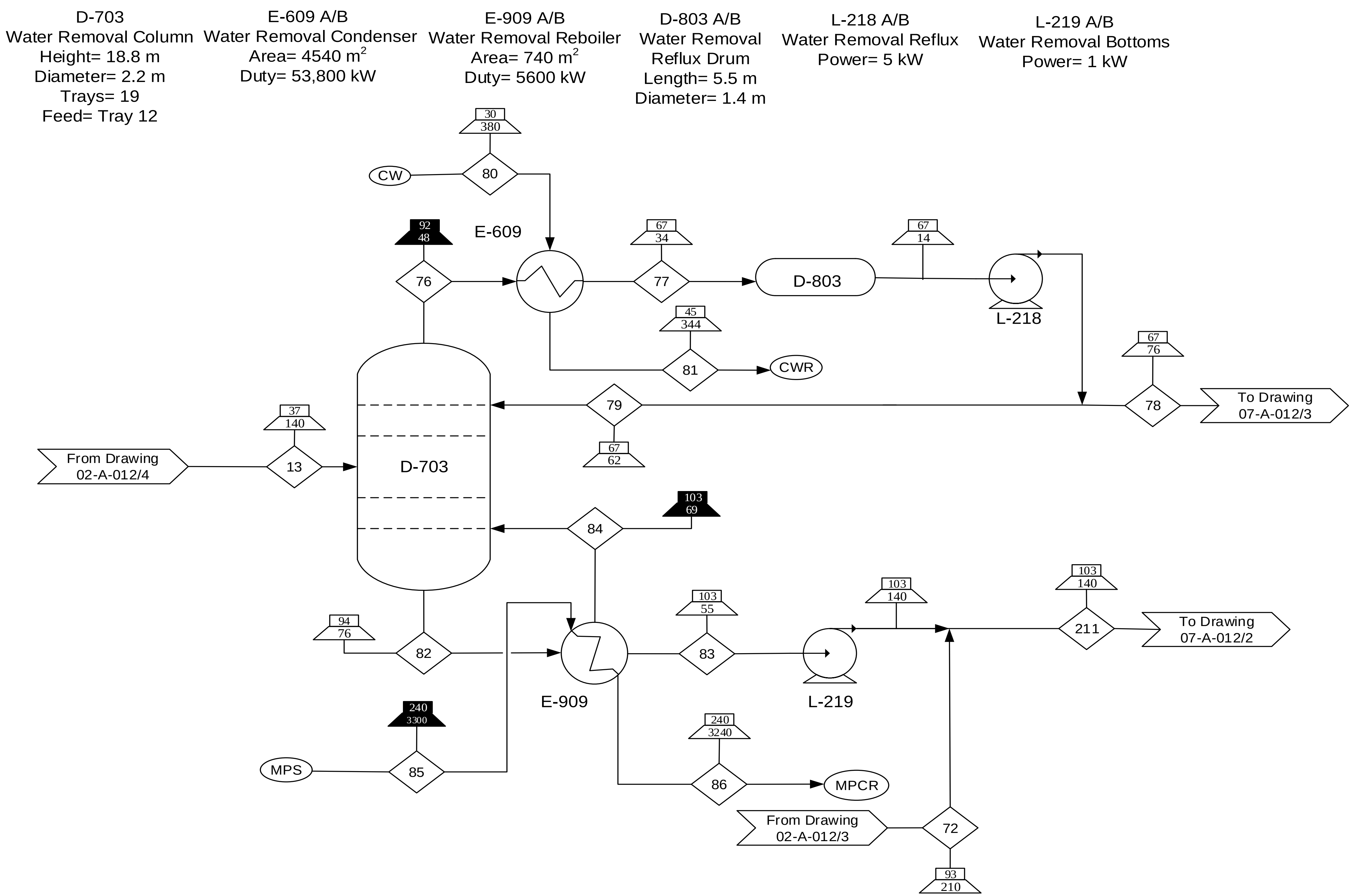
Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase
MPS Medium Pressure Steam
MPCR Medium Pressure Condensate Recycle
CW Cooling Water
CWR Cooling Water Recycle
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

Reference Drawings:
Process Flow Diagrams
04-A-012
05-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	05-A-012/4	0



Component/Stream (kg/min)	13	72	76	77	78	79	80	81	82	83	84	85	86	211
Fatty Acids C1-C18	140	0	0	0	0	0	0	0	360	130	240	0	0	130
Fatty Acids C2-C3	0	5	0	0	0	0	0	0	0	0	0	0	0	5
TMA	150	0	280	280	150	120	0	0	0	0	0	0	0	0
Water	630	0	1000	1000	590	450	50000	50000	86	31	54	1900	1900	31
Total	910	5	1300	1300	740	570	50000	50000	450	160	290	1900	1900	160

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
MPS Medium Pressure Steam
MPCR Medium Pressure Condensate Recycle
CW Cooling Water
CWR Cooling Water Recycle

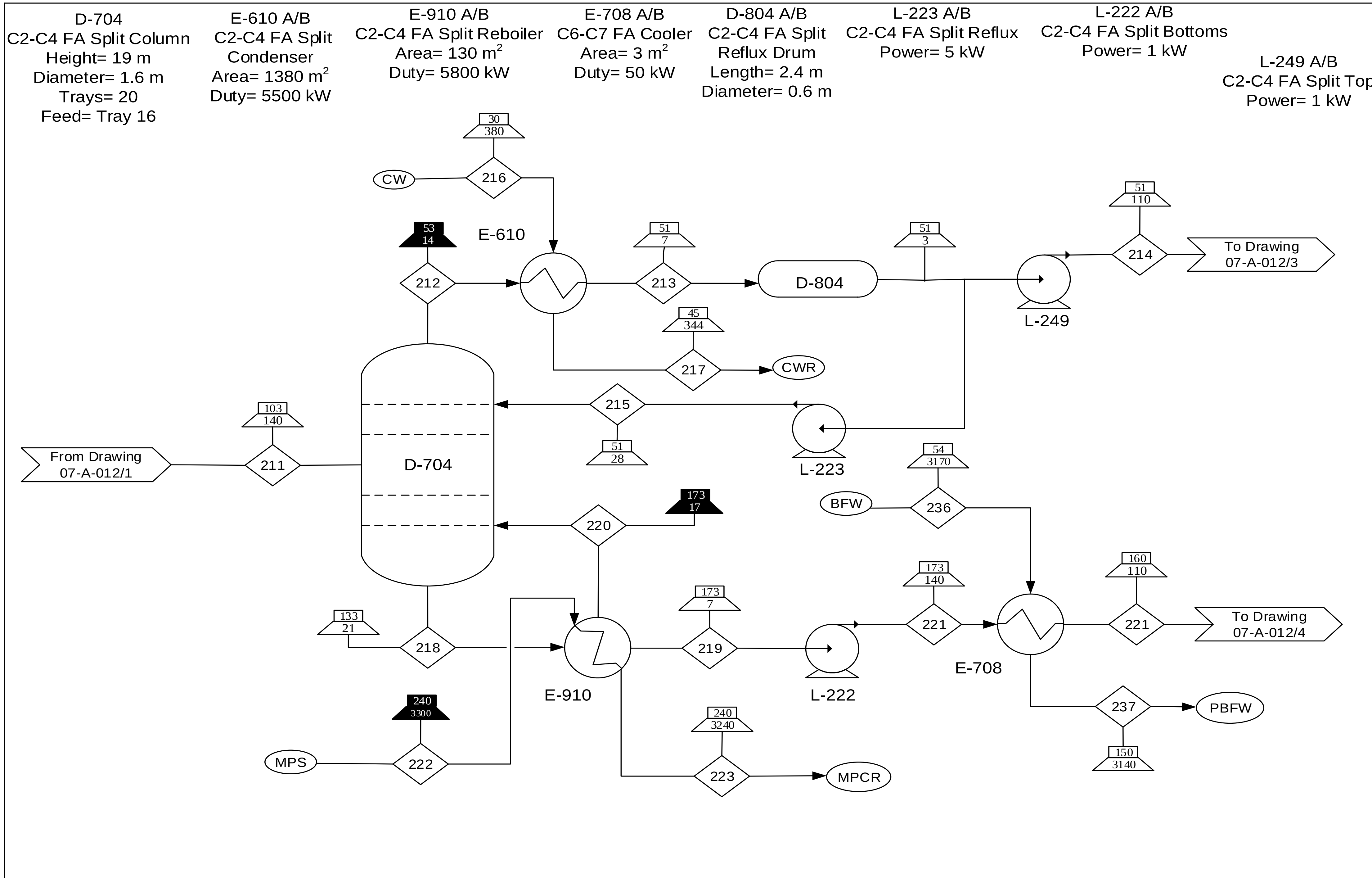
Reference Drawings:

Input/Output Diagram 00-A-010
Block Flow Diagram 00-A-011
Process Flow Diagrams 02-A-012, 07-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

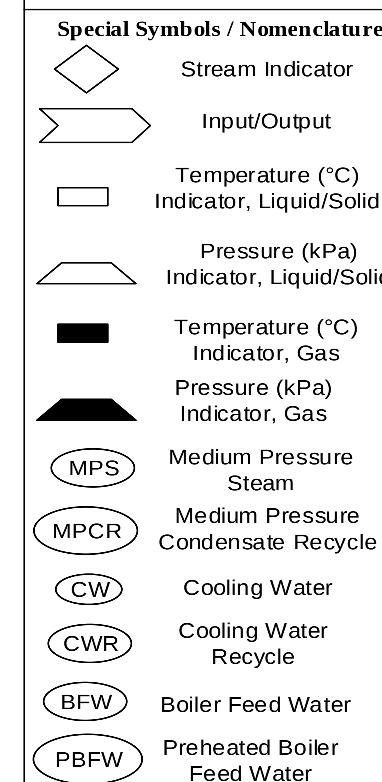
By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	07-A-012/1	0



Component/Stream (kg/min)	211	212	213	214	215	216	217	218	219	220	221	222	223	236	237
Fatty Acids C1-C18	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	0	23	23	5	18	0	0	0	0	0	0	0	0	0	0
Fatty Acids C3-C18	0	0	0	0	0	0	0	500	130	370	130	0	0	0	0
Water	31	100	100	31	68	5400	5400	0	0	0	0	200	200	54	54
Total	160	120	120	36	86	5400	5400	500	130	370	130	200	200	54	54

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.



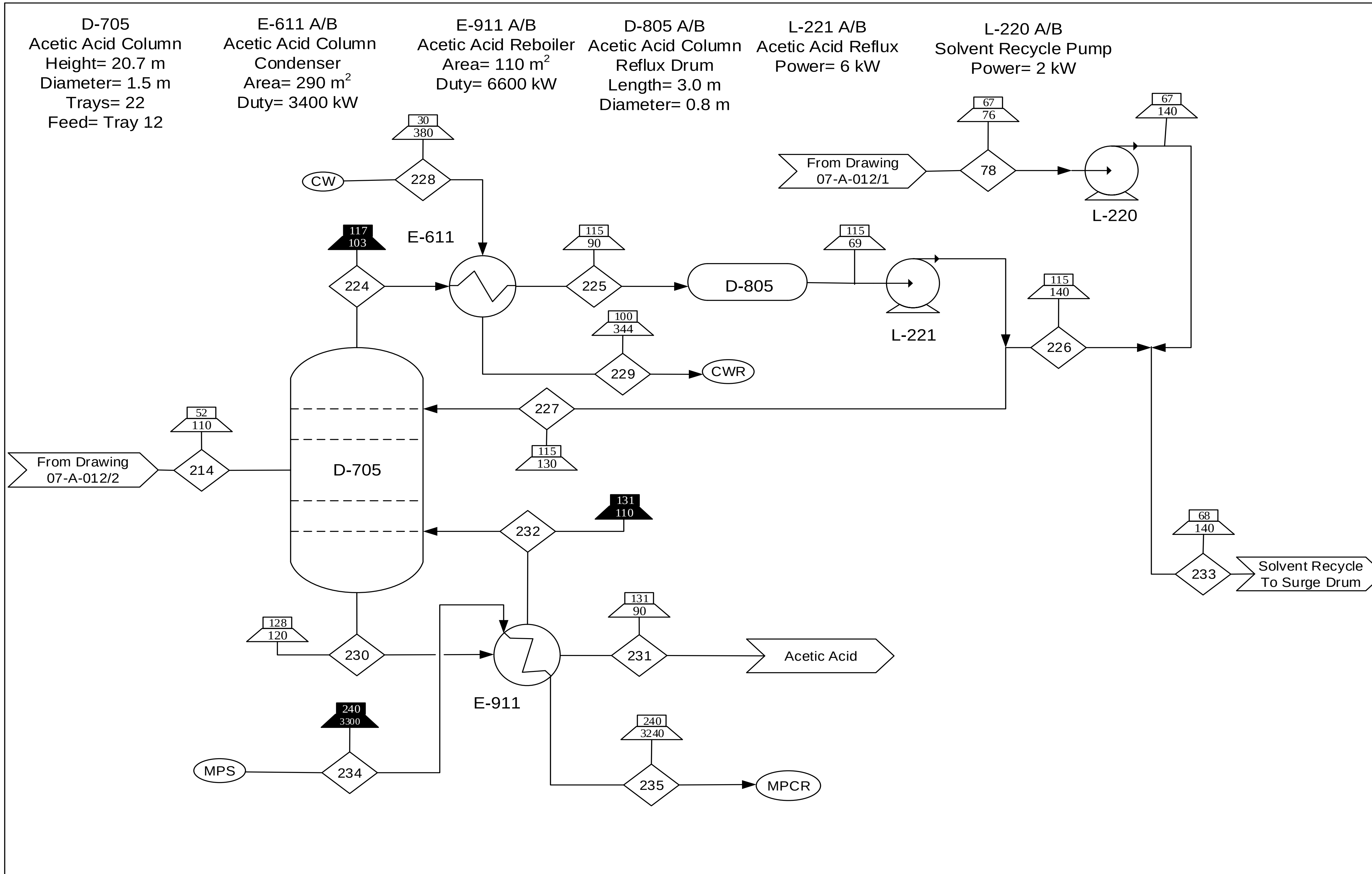
Reference Drawings:

Input/Output Diagram 00-A-010
Block Flow Diagram 00-A-011
Process Flow Diagrams 07-A-012

Drawing Type: Process Flow Diagram

Title: Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-012/2	0



Component/Stream (kg/min)	78	214	224	225	226	227	228	229	230	231	232	233	234	235
Acetic Acid	0	5	0	0	0	0	0	0	420	5	420	0	0	0
Propionic Acid	Trace	Trace	0	0	0	0	0	0	2	Trace	2	0	0	0
TMA	150	0	0	0	0	0	0	0	0	0	0	150	0	0
Water	590	31	140	140	31	110	5900	5900	0	0	0	640	220	220
Total	730	36	140	140	31	110	5900	5900	420	5	420	770	220	220

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- MPS: Medium Pressure Steam
- MPCR: Medium Pressure Condensate Recycle
- CW: Cooling Water
- CWR: Cooling Water Recycle

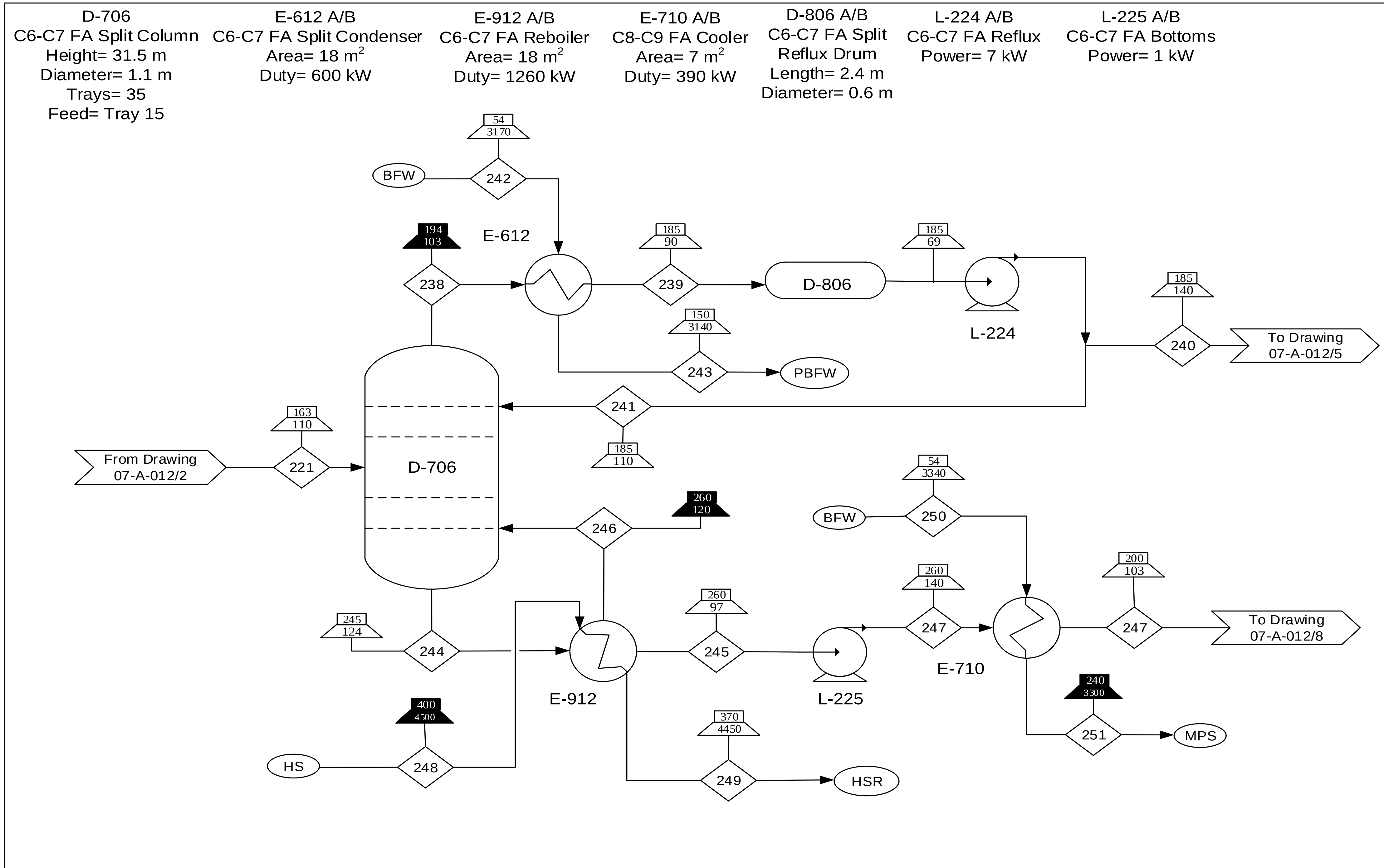
Reference Drawings:

Input/Output Diagram 00-A-010
Block Flow Diagram 00-A-011
Process Flow Diagrams 07-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-012/3	0



Component/Stream (kg/min)	221	238	239	240	241	242	243	244	245	246	247	248	249	250	251
Fatty Acids C3-C18	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fatty Acids C3-C6	0	59	59	10	50	0	0	0	0	0	0	0	0	0	0
Fatty Acids C7-C18	0	0	0	0	0	0	0	250	120	140	120	0	0	0	0
Water	0	0	0	0	0	590	590	0	0	0	0	430	430	9	9
Total	130	59	59	10	50	590	590	250	120	140	120	430	430	9	9

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

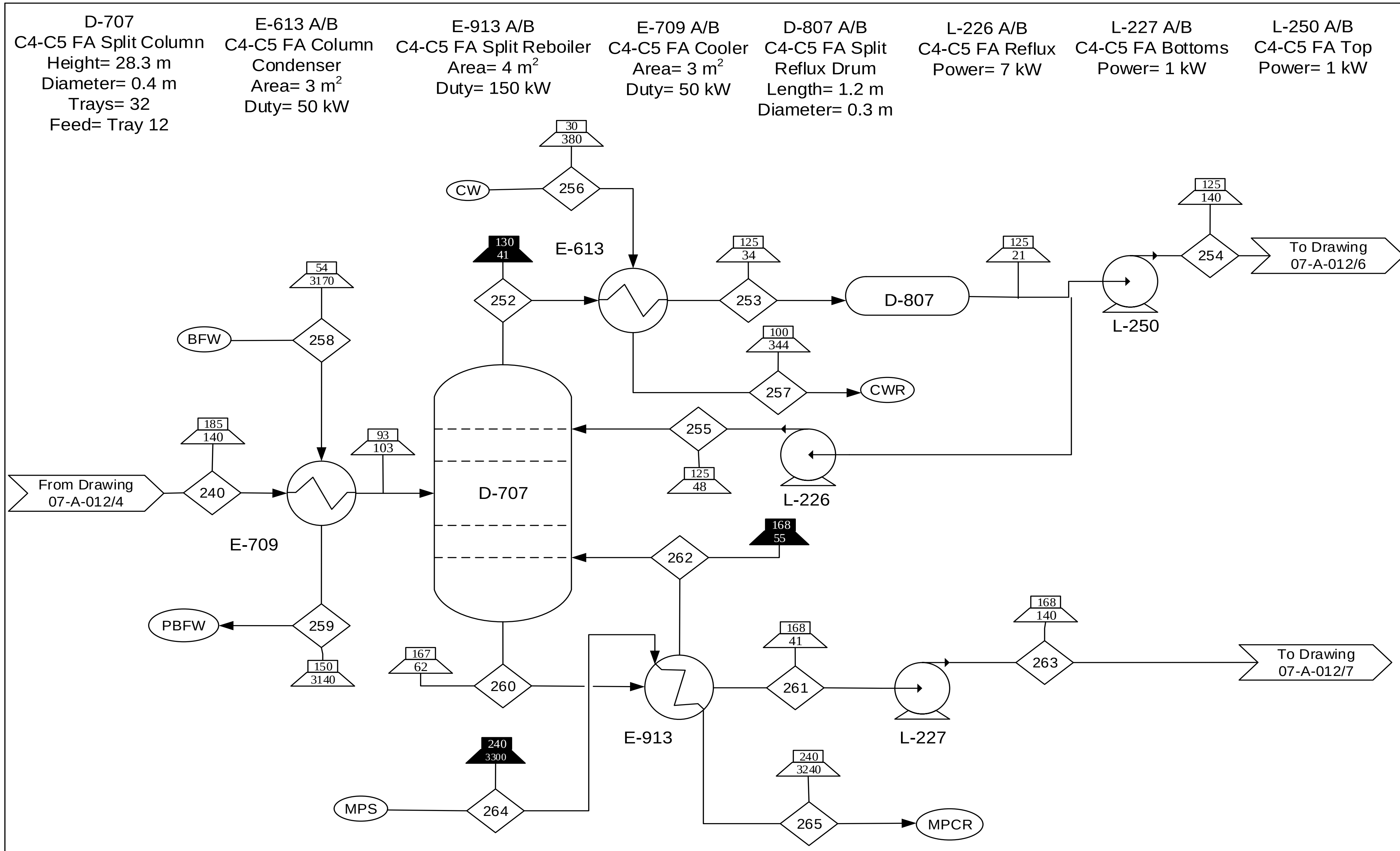
Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
MPS Medium Pressure Steam
HS High Pressure Steam
HSR High Pressure Steam Recycle
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

Reference Drawings:
Input/Output Diagram 00-A-010
Block Flow Diagram 00-A-011
Process Flow Diagrams 07-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-012/4	0



Component/Stream (kg/min)	240	252	253	254	255	256	257	258	259	260	261	262	263	264	265
Fatty Acids C3-C6	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fatty Acids C3-C4	0	10	10	2	8	0	0	0	0	0	0	0	0	0	0
Fatty Acids C5-C6	0	0	0	0	0	0	0	0	0	24	9	15	9	0	0
Water	0	0	0	0	0	110	110	45	45	0	0	0	0	5	5
Total	10	10	10	2	8	110	110	45	45	24	9	15	9	5	5

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
MPS Medium Pressure Steam
MPCR Medium Pressure Condensate Recycle
CW Cooling Water
CWR Cooling Water Recycle
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram 00-A-010
Block Flow Diagram 00-A-011
Process Flow Diagrams 07-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-012/5	0

D-708
C3-C4 FA Product Column
Height= 24.7 m
Diameter= 0.3 m
Trays= 28
Feed= Tray 15

E-614 A/B
C4-C5 FA Column Condenser
Area= 3 m^2
Duty= 50 kW

E-914 A/B
C3-C4 FA Product Reboiler
Area= 2 m^2
Duty= 71 kW

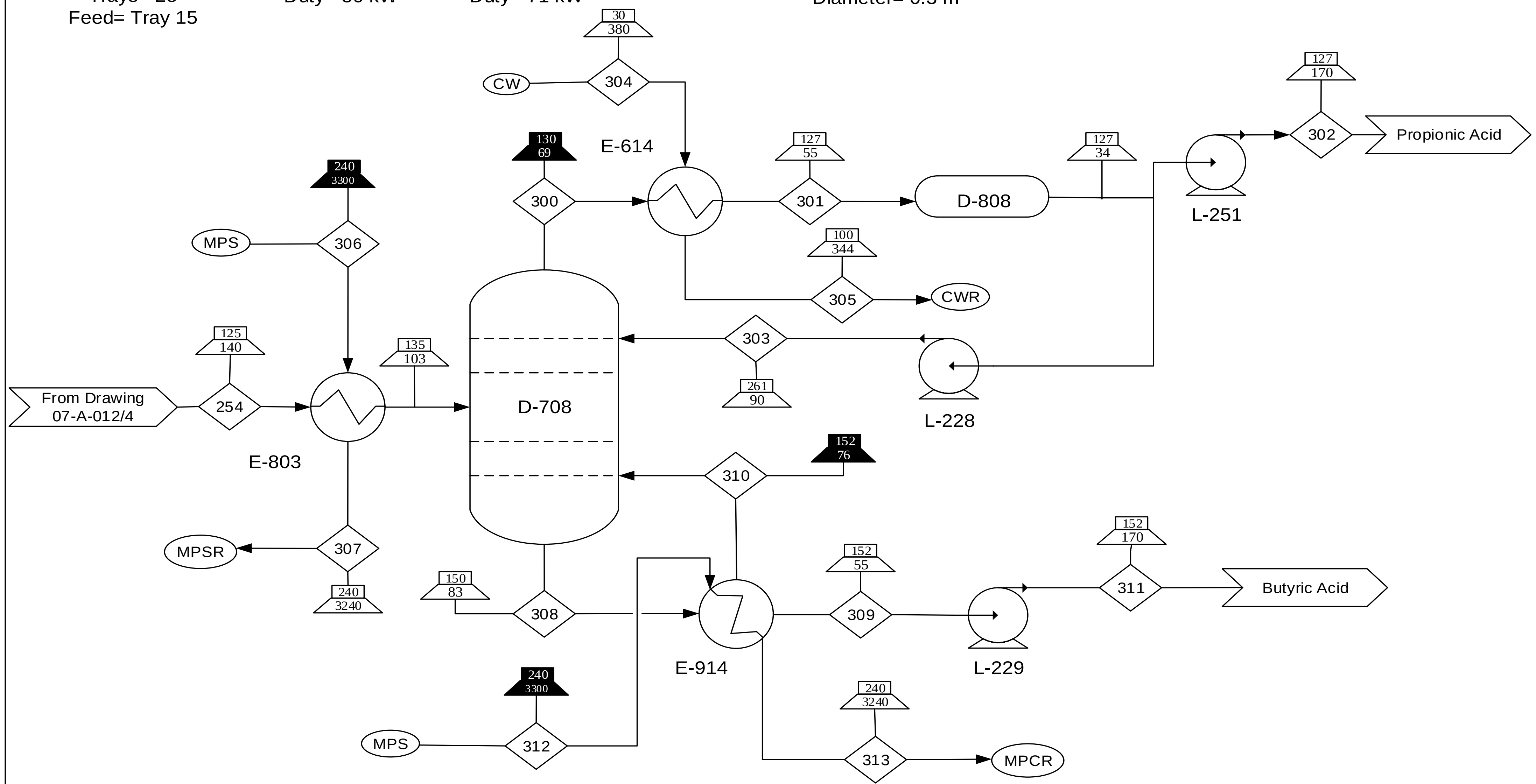
E-803 A/B
C3-C4 FA Heater
Area= 1 m^2
Duty= 8 kW

D-808 A/B
C3-C4 FA Product Reflux Drum
Length= 1.2 m
Diameter= 0.3 m

L-228 A/B
C3-C4 FA Reflux
Power= 6 kW

L-229 A/B
C3-C4 FA Bottoms
Power= 1 kW

L-251 A/B
C3-C4 FA Top
Power= 1 kW



Component/Stream (kg/min)	254	300	301	302	303	304	305	306	307	308	309	310	311	312	313
Fatty Acids C3-C4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	0	5	5	1	5	0	0	0	0	0	0	0	0	0	0
Butyric Acid	0	0	0	0	0	0	0	0	0	7	1	6	1	0	0
Water	0	0	0	0	0	68	68	1	1	0	0	0	0	2	2
Total	2	5	5	1	5	68	68	1	1	7	1	6	1	2	2

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- MPS — Medium Pressure Steam
- MPCR — Medium Pressure Condensate Recycle
- CW — Cooling Water
- CWR — Cooling Water Recycle
- BFW — Boiler Feed Water
- PBFW — Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
07-A-012

Drawing Type

Process Flow Diagram

Title

Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-012/6	0

D-709
C5-C6 FA Product Column
Height= 26.7 m
Diameter= 0.6 m
Trays= 30
Feed= Tray 15

E-615 A/B
C5-C6 FA Product Condenser
Area= 9 m^2
Duty= 270 kW

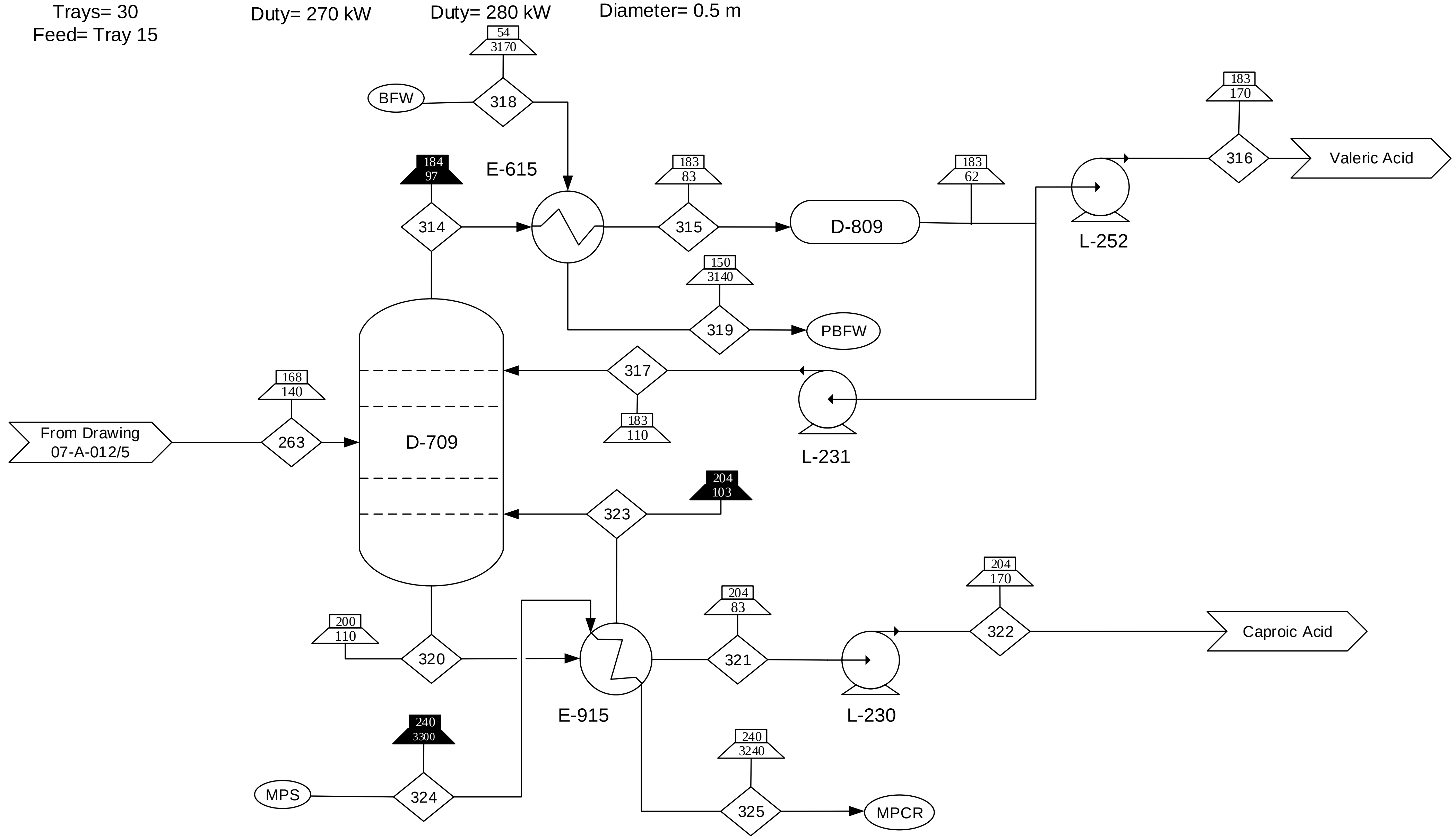
E-915 A/B
C5-C6 FA Product Reboiler
Area= 15 m^2
Duty= 280 kW

D-809 A/B
C5-C6 FA Product Reflux Drum
Length= 1.8 m
Diameter= 0.5 m

L-231 A/B
C5- C6 FA Reflux
Power= 6 kW

L-230 A/B
C5-C6 FA Bottoms
Power= 1 kW

L-252 A/B
C5-C6 FA Top
Power= 1 kW



Component/Stream (kg/min)	263	314	315	316	317	318	319	320	321	322	323	324	325
Fatty Acids C5-C6	9	0	0	0	0	0	0	0	0	0	0	0	0
Valeric Acid	0	27	27	3	24	0	0	0	0	0	0	0	0
Caproic Acid	0	0	0	0	0	0	0	36	5	5	31	0	0
Water	0	0	0	0	0	260	260	0	0	0	0	10	10
Total	9	27	27	3	24	260	260	36	5	5	31	10	10

Notes

1. Drawing is not to scale.

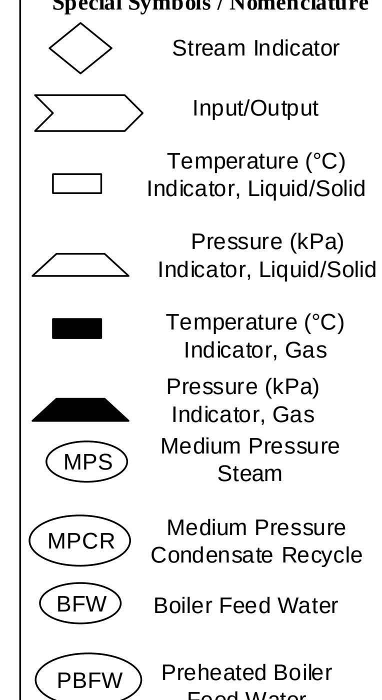
2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

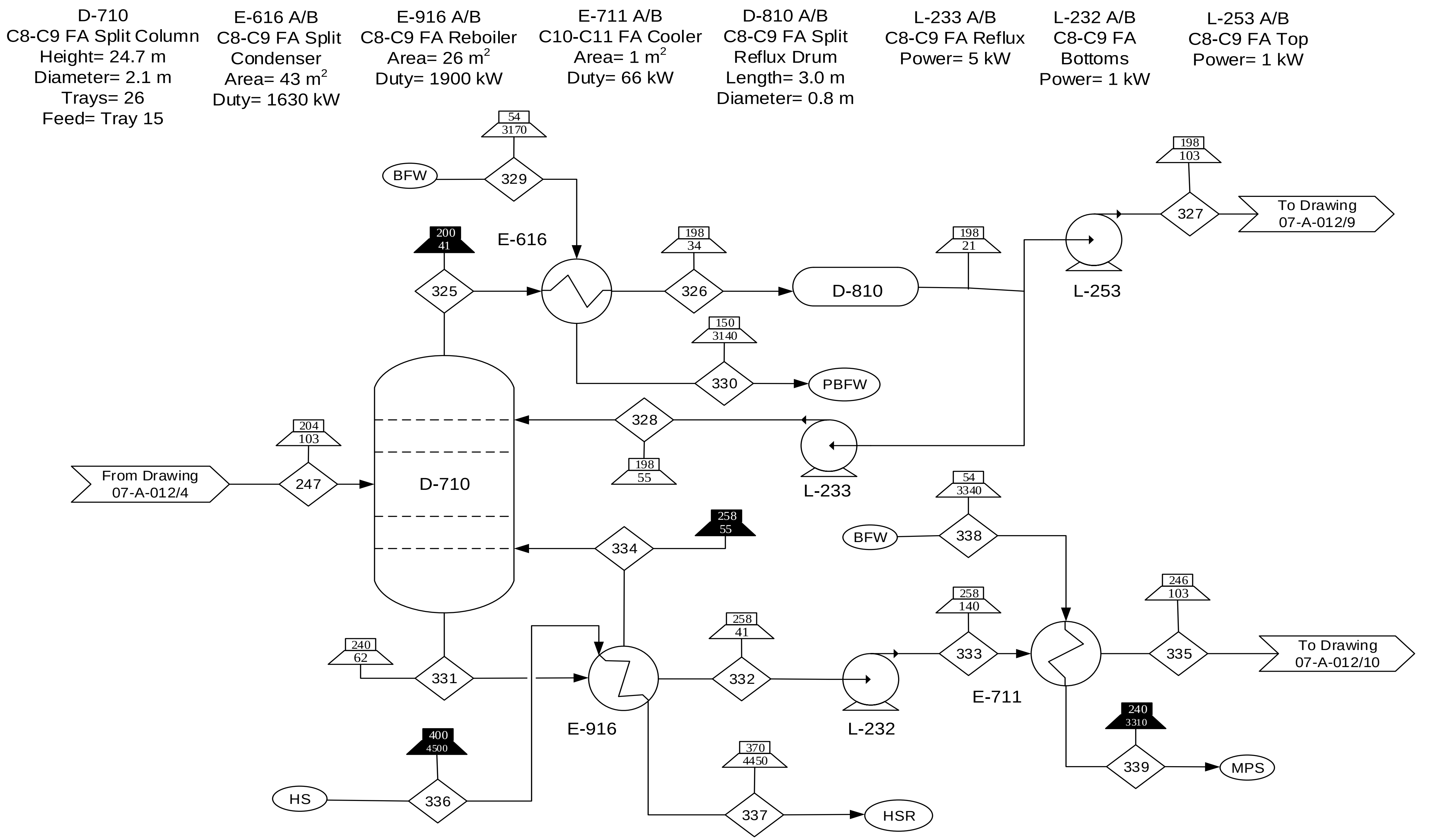
Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
07-A-012

Drawing Type		
Process Flow Diagram		
Title: Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section		
By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-012/7	0



Component/Stream (kg/min)	247	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339
Fatty Acids C7-C18	120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fatty Acids C7-C8	0	190	190	26	160	0	0	0	0	0	0	0	0	0	0	0
Fatty Acids C9-C18	0	0	0	0	0	0	0	320	91	91	230	91	0	0	0	0
Water	0	0	0	0	0	1500	1500	0	0	0	0	0	640	640	2	2
Total	120	190	190	26	160	1500	1500	320	91	91	230	91	640	640	2	2

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- MPS — Medium Pressure Steam
- HS — High Pressure Steam
- HSR — High Pressure Steam Recycle
- BFW — Boiler Feed Water
- PBFW — Preheated Boiler Feed Water

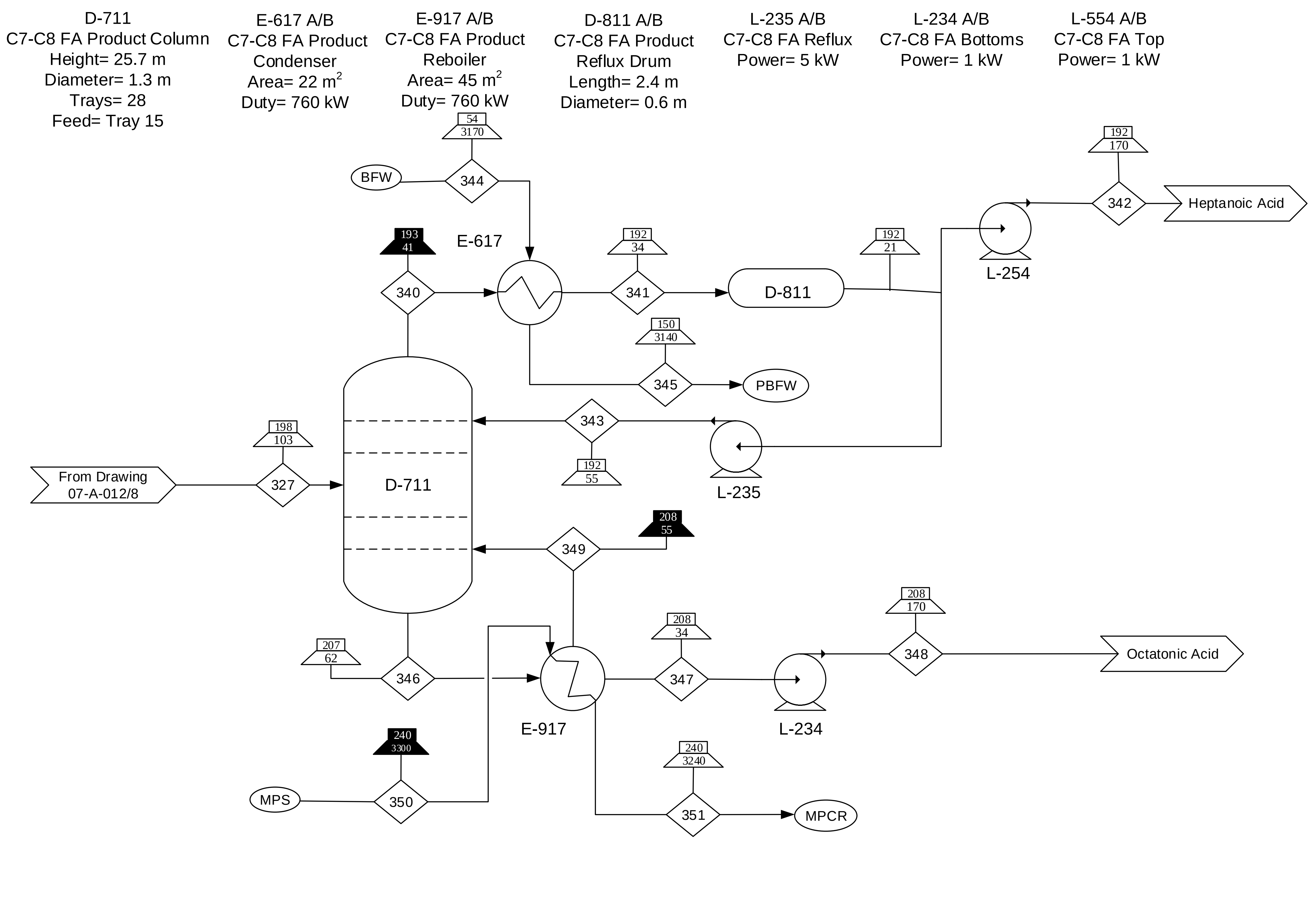
Reference Drawings:

Input/Output Diagram 00-A-010
Block Flow Diagram 00-A-011
Process Flow Diagrams 07-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-012/8	0



Component/Stream (kg/min)	327	340	341	342	343	344	345	346	347	348	349	350	351
Fatty Acids C7-C8	26	0	0	0	0	0	0	0	0	0	0	0	0
Heptanoic Acid	0	86	86	15	73	0	0	0	0	0	0	0	0
Octanoic Acid	0	0	0	0	0	0	0	100	11	11	95	0	0
Water	0	0	0	0	0	730	730	0	0	0	0	26	26
Total	26	86	86	15	73	730	730	100	11	11	95	26	26

Notes
1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature
- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- MPS: Medium Pressure Steam
- MPCR: Medium Pressure Condensate Recycle
- BFW: Boiler Feed Water
- PBFW: Preheated Boiler Feed Water

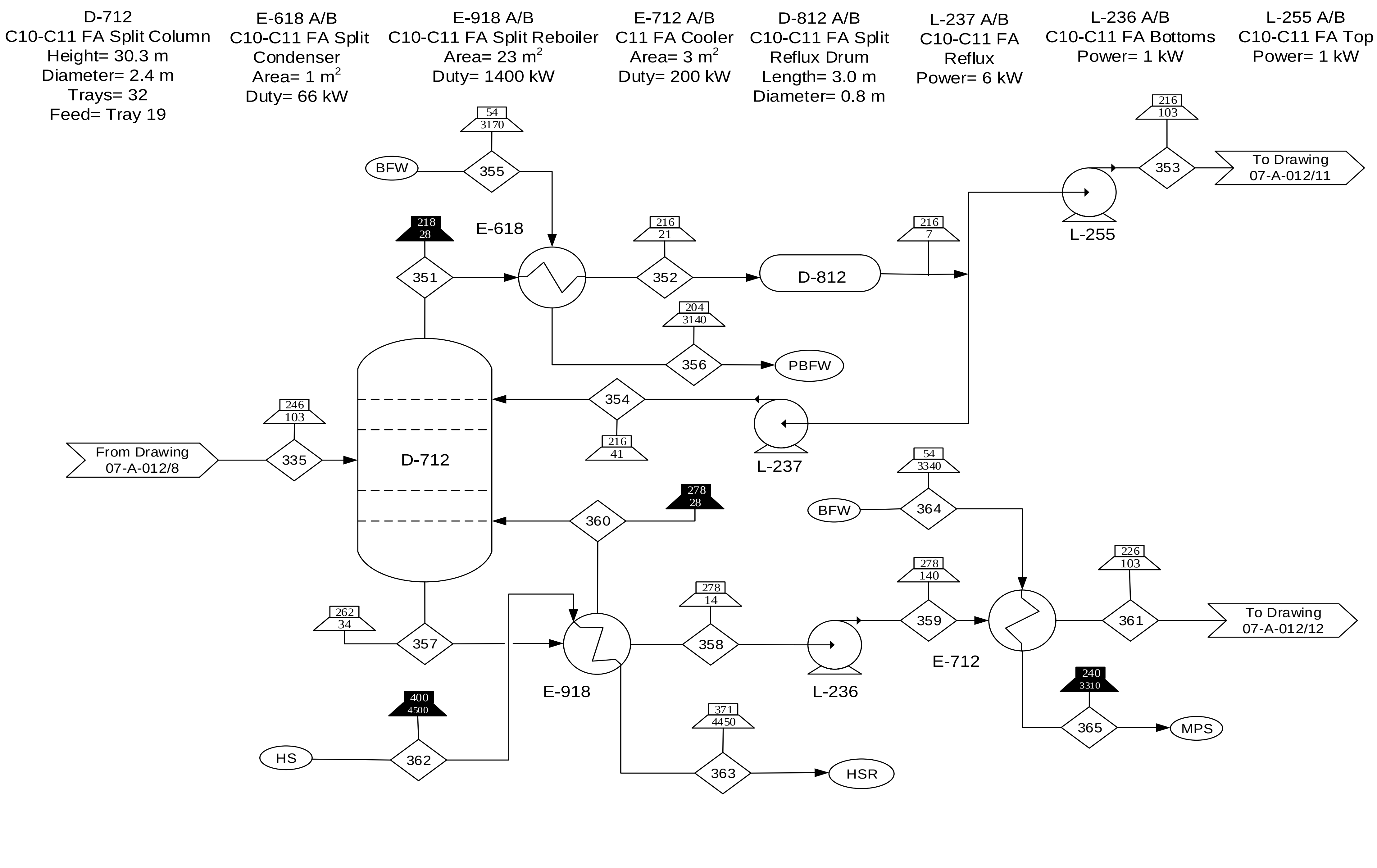
Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
07-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-012/9	0



Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- MPS: Medium Pressure Steam
- HS: High Pressure Steam
- HSR: High Pressure Steam Recycle
- BFW: Boiler Feed Water
- PBFW: Preheated Boiler Feed Water

Reference Drawings:

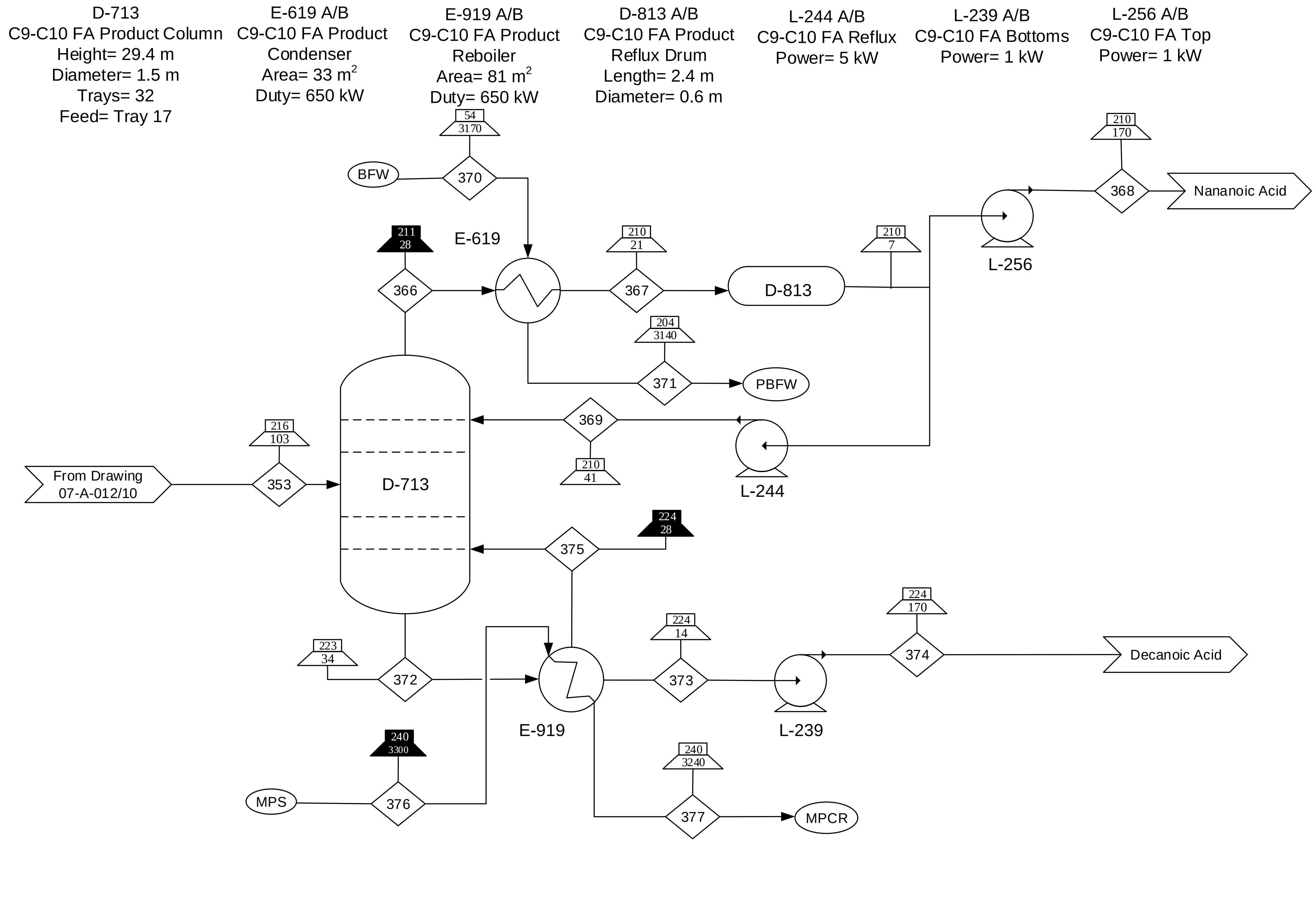
Input/Output Diagram 00-A-010
Block Flow Diagram 00-A-011
Process Flow Diagrams 07-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-012/10	0

Component/Stream (kg/min)	335	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365
Fatty Acids C9-C18	91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fatty Acids C9-C10	0	170	170	24	150	0	0	0	0	0	0	0	0	0	0	0
Fatty Acids C11-C18	0	0	0	0	0	0	0	250	68	68	190	68	0	0	0	0
Water	0	0	0	0	0	120	120	0	0	0	0	0	500	500	5	5
Total	91	170	170	24	150	120	120	250	68	68	190	68	500	500	5	5



Component/Stream (kg/min)	353	366	367	368	369	370	371	372	373	374	375	376	377
Fatty Acids C9-C10	24	0	0	0	0	0	0	0	0	0	0	0	0
Nananoic Acid	0	82	82	14	68	0	0	0	0	0	0	0	0
Decanoic Acid	0	0	0	0	0	0	0	100	11	11	86	0	0
Water	0	0	0	0	0	59	59	0	0	0	0	23	23
Total	24	82	82	14	68	59	59	100	11	11	86	23	23

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- MPS — Medium Pressure Steam
- MPCR — Medium Pressure Condensate Recycle
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- PBFW — Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
07-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-012/11	0

D-714
C11 FA Product Column
Height= 27.8 m
Diameter= 1.7 m
Trays= 30
Feed= Tray 17

E-620 A/B
C11 FA Product Condenser
Area= 18 m^2
Duty= 430 kW

E-920 A/B
C11 FA Product Reboiler
Area= 81 m^2
Duty= 650 kW

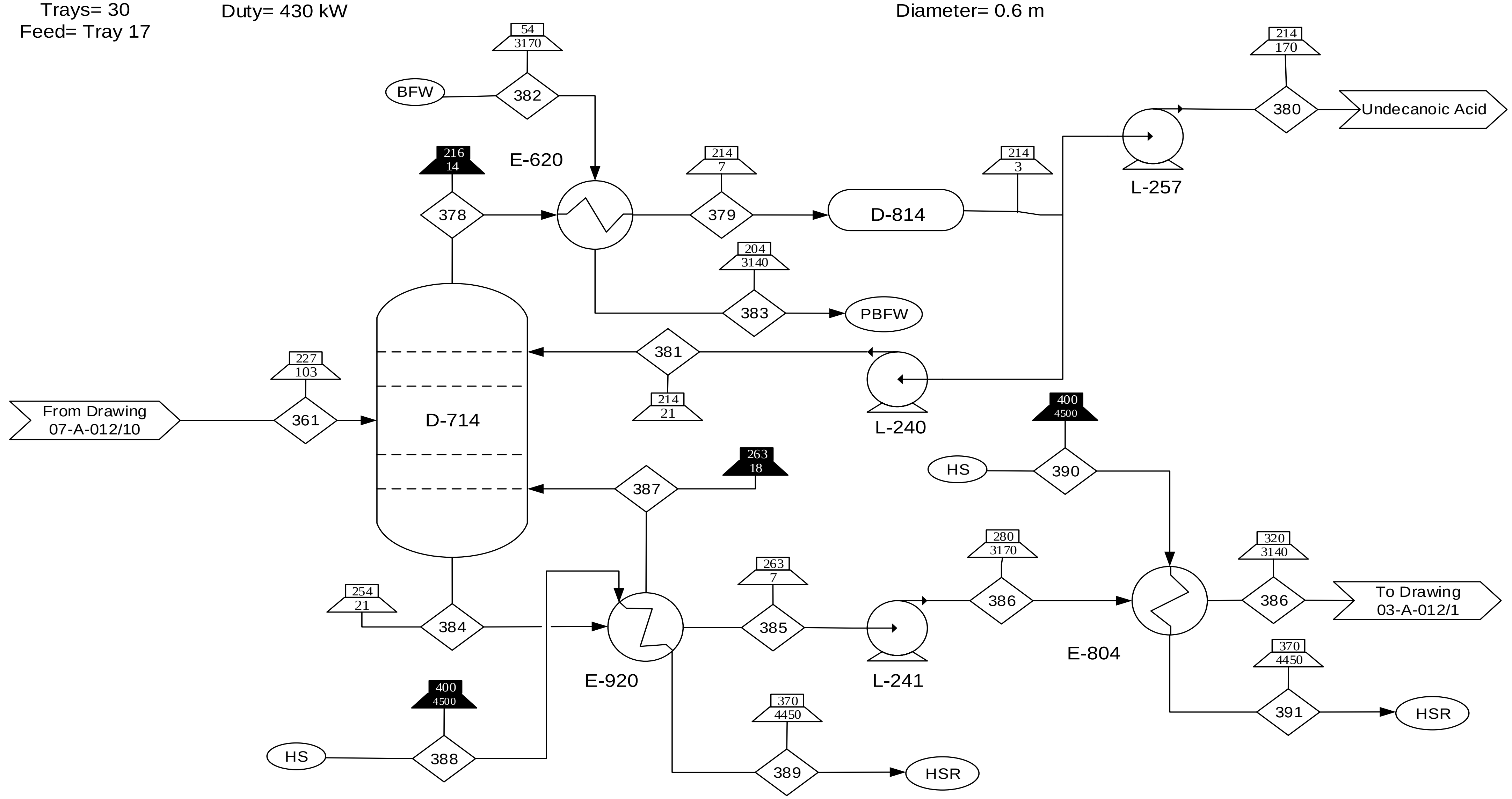
E-804 A/B
Fatty Acid Decarbox Heater
Area= 6 m^2
Duty= 200 kW

D-814 A/B
C11 FA Product Reflux Drum
Length= 2.4 m
Diameter= 0.6 m

L-240 A/B
C11 FA Reflux
Power= 5 kW

L-241 A/B
C11 FA Bottoms
Power= 7 kW

L-257 A/B
C11 FA Top
Power= 2.5 kW



Component/Stream (kg/min)	361	378	379	380	381	382	383	384	385	386	387	388	389	390	391
Fatty Acids C11-C18	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undecanoic Acid	0	59	59	5	54	0	0	0	0	0	0	0	0	0	0
Fatty Acids C12-C18	0	0	0	0	0	0	0	140	64	64	77	0	0	0	0
Water	0	0	0	0	0	41	41	0	0	0	0	190	190	68	68
Total	68	59	59	5	54	41	41	140	64	64	77	190	190	68	68

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- HS — High Pressure Steam
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- BFW — Boiler Feed Water
- PBFW — Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-010
Block Flow Diagram
00-A-011
Process Flow Diagrams
03-A-012
07-A-012

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-012/12	0

Chapter V

HEAVY END PROCCESSING – MESOPHASE PITCH

The heavy end processing design includes the base design for a biorefinery based on the noncatalytic cracking of TAG oils that produces transportation fuels and limited byproducts, as well as processing the vacuum bottoms into a mesophase pitch byproduct. This biorefinery is designed as a world scale processing plant capable of producing renewable transportation fuels, and hopefully help to lower the dependence upon petroleum-based transportation fuels.

The following sections describe the process used to develop a preliminary design and economic assessment for the design of a biorefinery that processes the heavy ends into the saleable byproduct of mesophase pitch. Section V.A. analyses the differences between the heavy end processing design compared to the base design presented in Chapter III of this thesis. Section V.B reviews the preliminary design of the biorefinery, Section V.C describes the economic assessment performed based on this design, and Section V.D examines the profitability of the process and describes possible ways to increase its profitability.

V.A. Differences from the Base Design

The heavy end processing design takes the vacuum bottoms that are produced in the base design and processes them into the saleable byproduct of mesophase pitch. The processing of the vacuum bottoms requires an additional section to be added to the plant, the heavy end processing section. This section includes the pitching reactor, and additional heat exchangers and conveyors, which process the vacuum tars into mesophase pitch and recovers additional fuel oil no. 5.

These changes from the base design result in significant changes in the economics of the plant. The heavy end processing section not only is an additional major unit operation, the pitching reactor and conveyors require significant amounts of power and heating duty. This increased duty results in the heavy end processing design requiring significantly larger boilers.

This in turn results in an increase of $10 million ± 40% to the total capital investment compared to the base design. The additional unit operations also results in increased operating labor and maintenance for the plant.

V.B. Process Design

The design provided is specifically based on a feed of soybean oil. However, any triglyceride (TG) oil, unsaturated fatty acid, or carboxylic acid (e.g. lipids) can be used. Differences in the product rates and slight differences in the reaction temperatures are the only expected variations based on feedstock. A 7500 MTPD soybean oil extraction plant can efficiently produce 600,000 m^3/year of crude soybean oil [56]. The typical composition of this soybean oil can be found in Table 71. The crude soybean oil feed, shown in Table 72, can then be noncatalytically cracked into naphtha which is a gasoline blend compound, plus transportation fuel quality kerosene and diesel oils. Kerosene is the primary compound of jet fuel. The flow rates of the most significant products can be found in Table 73. All products produced are in compliance with the fuel ASTM standards. The properties of these streams can be found in Tables 74-76. Other possibilities, not directly addressed in this design are other kerosene products and diesel no. 1.

In addition to the production of transportation fuels, the byproducts of butane, mesophase pitch, and acetic acid are produced. The flow rates of all byproducts can be found in Table 77, and the ASTM properties of butane can be found in Table 78. This process also produces two streams that are used as boiler feed for the plant. These streams can be found in Table 79. The input/output diagram (Drawing 00-A-016) shows the overall mass balance and mass flow rates of the inputs and outputs to the process.

Catalyst is used in the decarboxylation reactions, and is used to convert the carboxylic acids that are produced during the noncatalytic cracking of the soybean oil into alkanes. The amount of catalyst used for the process can be found in Table 80, and the utilities required are presented in Table 81.

The process was designed as four core subsystems. The first subsystem consists of the thermal cracking section. In this section the incoming soybean oil is cracked into a three phase product through the use of noncatlytic cracking at high temperatures. The majority of the molecules are cracked into the C5-C16 range. The next subsystem is the purification section. In this section the light ends and heavy ends are separated from the middle distillates, which are known as organic liquid product (OLP). The OLP is then sent through the next subsection, decarboxylation. In this area the carboxylic acids are converted into hydrocarbons and the alkenes are hydrogenated into alkanes through the use of steam. Following decarboxylation, the OLP's are sent to the final subsystem, trim purification. In this section the OLP's are purified into transportation fuel products, and the light ends and heavy ends are purified into saleable byproducts.

All separation and reaction unit operations that are required for the process are shown in the quantitative block flow diagram (BFD). This drawing also shows the mass balance for the individual process areas. The thermal cracking and purification subsections are shown on Drawing 00-A-017/sheet 1, and the decarboxylation and trim purification subsections are shown on sheets 2-5.

Drawings 0X-A-018/X show the process flow diagrams for the process. The following detailed process description is based off of the process flow diagrams. Table 82 displays the equipment lettering system, Table 83 shows the equipment number codes, and Table 84 presents an example equipment number scheme. These tables explain how the equipment in Tables 85-94 were coded. Table I.6 in Appendix I shows examples of all the equipment used in the drawings. Table 95 shows the drawing number codes, and Table 96 displays an example of how the drawings are named.

V.B.1. Thermal Cracking Section (Drawings 01-A-018/X)

TG oil is assumed to enter the process from storage at 1000 kg/min, a temperature of 20 °C, and a pressure of 140 kPa (stream 1). In order to heat the incoming oil to the desired temperature (410 °C) it is first sent through the post cracking cooler (E-201 A/B). This heat exchanger uses the excess heat of the products coming out of the TTCR (R-101) in stream 11 to preheat the feed. E-201 A/B heats the oil to 310 °C, and then it is pressurized to the reaction pressure of 1930 kPa by L-101 A/B. Following the pre-cracking pump, the oil is heated to the desired temperature of 410 °C in E-502 A/B. The soybean oil then enters the TTCR (R-101) in Stream 8 on Drawing 01-A-018/2 at 410 °C and 1900 kPa.

The Turbulent Tubular Cracking Reactor is used to noncatalytically crack the TG oil into transportation fuel intermediates. The majority of these molecules are in the C5-C16 carbon number range. This reactor was designed to be 6.1 m in diameter and 12.2 m in length with 10300 tubes. It operates at a temperature of 430 °C and 1800 kPa, and has a residence time of 1.17 hr. The soybean oil and crackate flow through the tube side of the reactor, and the superheated steam (435 °C and 6000 kPa) that heats the reactor flows through the shell side. The products leaving the reactor are used to heat the incoming soybean oil in E-101 A/B, and are then sent to the purification section of the plant in Stream 12 at 1000 kg/min, 230 °C, and 1760 kPa.

V.B.2. Purification Section (Drawings 02-A-018/X)

Following the thermal cracking section of the plant is the purification section. In this section the middle distillates are separated from the light and heavy ends, and the fatty acids are removed from the middle distillates. First, the cooled TTCR products (Stream 12) are sent to the acetic acid separator 1 (D-107). In this flash drum the majority of the C1-C8 carbon length molecules (Stream 17) are flashed off of the remaining C7-C50 molecules by flashing the incoming stream to 1380 kPa. In addition to the removal of the lighter compounds, some of the acetic acid that is produced in the TTCR separates out from the organic phase. This aqueous acetic acid, with small amounts of propionic acid, are removed from the organic liquid product in Stream 15. The organic liquid is then flashed again in D-101 at 690 kPa. In this flash drum the remaining lighter molecules are removed in Stream 19, leaving the liquid products in Stream 18. Streams 17 and 19 are then sent to D-108 on Drawing 02-A-018/3, and Stream 18 is sent to E-202 A/B on Drawing 02-A-018/2.

Stream 18 is first cooled to 150 °C in E-202 A/B, and is then flashed a third time in D-102. This flash drum operates at 140 kPa. The liquid products are then sent to the atmospheric distillation column on Drawing 02-A-018/4 in Stream 23. The gas products from D-102 are first compressed by G-101 A/B to 410 kPa, and are then sent to D-108 on Drawing 02-A-018/3 in Stream 25.

Streams 17 and 19 from sheet 1 are sent into acetic flash drum 2 on Drawing 02-A-018/3. Stream 25 from G-101 on sheet 2 is also sent into this flash drum. D-108 removes the light ends in the C1-C6 carbon range in the gas product in Stream 56. The remaining C6-C8 organic liquid is removed in Stream 57. D-108 also has a small amount of acetic and propionic acid, which separate out from the organic liquid phase into an aqueous phase. This product (Stream 58) is combined with Stream 15 in D-310 to form Stream 72, the acetic acid byproduct stream at 5 kg/min. From D-108, stream 56 is sent to D-105 on Drawing 05-A-018/1 for light end purification. Stream 57, the C6-C8 organic liquid, is sent to combine with the tops from the atmospheric distillation column (D-201) as shown on Drawing 03-A-018/1.

The atmospheric distillation column (D-201), shown on Drawing 02-A-018/4, separates the naphtha/kerosene range fuel intermediates from the heavier diesel fuel range intermediates. D-201 splits the incoming Stream 23 at the C12-C13 carbon range. The distillate products (C7-C12) leave the top of the column at 210 °C and 124 kPa. They are first condensed at 60 °C in E-101 A/B and pressurized to 140 kPa by L-104 A/B prior to combining with Stream 57 on Drawing 03-A-018/1. The bottoms from D-201 exit the column at 280 °C and 140 kPa. They are then heated to 310 °C in E-401 A/B and are then sent to vacuum distillation column D-202 as Stream 33 at 590 kg/min. D-201 is 8.4 m tall, 2.4 m in diameter, and has 7 trays. The feed enters the column at tray 3, and the column operates with a reflux ratio of 0.1.

Stream 33 enters the vacuum column (D-202) on Drawing 02-A-018/5 at tray 5. D-202 operates at 30 kPa, and has a height of 20 m, diameter of 2.9 m, and 20 trays. D-202 separates the diesel range fuel intermediates from the heavy end byproducts. This separation occurs at the C30 range, with the diesel fuel intermediates leaving in the distillate (C12-C30), and the heavy ends leaving the bottom (C30-C50). The distillate leaves D-202 at 315 °C and 21 kPa. It is then cooled to 230 °C in E-102 A/B. The reflux is then sent back to the column at a reflux ratio of 1.3, and the distillates head to decarboxylation in R-102 at 230 °C, 140 kPa and 320 kg/min in Stream 49. The bottoms exit D-202 at 330 °C and 35 kPa. They are then heated to 340 °C in E-402 A/B, and sent to heavy end processing shown on Drawing 06-A-018/1 at a rate of 280 kg/min in stream 41.

V.B.3. Decarboxylation Section (Drawings 03-A-018/X)

Stream 57 from D-108 on Drawing 02-A-018/3 and Stream 29 from L-104 A/B on Drawing 02-A-018/4 combine to form Stream 59 (220 kg/min) prior to being sent through the naphtha decarboxylation reactor (R-102 A/B). These streams combine to 60 °C and 140 kPa, and are then pressurized to 2400 kPa by L-103 A/B. Next, the stream is heated to the reaction temperature of 320 °C by E-503 A/B. Process steam at 315 °C and 2200 kPa also enters the reactor at a flow rate of 7 kg/min to provide a hydrogen donor source. The steam and feed stream react in R-102 A/B to convert any carboxylic acids that were produced from the noncatlytic cracking in R-101 into alkanes. The steam also reacts with a majority of the alkene molecules and forms alkanes of the same carbon chain length. This results in a significant amount of CO2 produced, as well as smaller fuel intermediate molecules (C1-C6). R-102 A/B is 2.9 m in diameter and 17 m in length with a catalyst volume of 220 m^3. The products exit the reactor in Stream 65 at 320 °C and 2200 kPa at a flow rate of 230 kg/min and proceed to E-209 A/B, shown on Drawing 03-A-018/3.

Stream 49 from L-108 A/B on Drawing 02-A-018/5 flowing at a rate of 320 kg/min is first pressurized to 2400 kPa by L-109 A/B, shown on Drawing 03-A-018/2. Then it is heated to 320 °C in E-504 A/B prior to entering the diesel decarboxylation reactor (R-103 A/B). Process steam in stream 70 also enters R-103 A/B at a flow rate of 10 kg/min at 315 °C and 2200 kPa. As in R-102 A/B, R-103 A/B reacts the feed stream with the process steam to convert any carboxylic acids and alkene molecules that were produced during the noncatalytic cracking into alkanes. R-103 A/B is 3.2 m in diameter and 19 m in length, with a catalyst volume of 310 m^3. The products exit the reactor in Stream 71 at 320 °C and 2200 kPa at a flow rate of 330 kg/min. They then proceed to E-208 A/B shown on Drawing 03-A-018/4, for removal of light end products that were formed in the reactor.

Stream 65 from R-102 A/B shown on Drawing 03-A-018/1 is first cooled to 93 °C by E-209 A/B prior to entering Flash 7 (D-109). D-109 flashes the incoming feed to 103 kPa, and separates the light components formed during decarboxylation (C1-C4) from the naphtha range fuel intermediates (C4-C12). The gas products from D-109 exit in Stream 4 at 77 °C and 103 kPa and head to light end purification shown on Drawing 05-A-018/1 at a flow rate of 45 kg/min. The liquid products exit D-109 at 77 °C and 103 kPa in Stream 3. They then combine with Stream 74 from D-105 on Drawing 05-A-018/1 to form Stream 78 at 200 kg/min. Stream 78 then proceeds to D-205 shown on Drawing 04-A-018/2 for trim purification after being pressurized to 140 kPa by L-128 A/B.

Stream 71 from R-103 A/B on Drawing 03-A-018/2 is first cooled to 180 °C by E-208 A/B as shown on Drawing 03-A-018/4. It is then sent to flash 3 (D-103) to remove the majority of the light end products. D-103 flashes the incoming stream from 2170 kPa to 1720 kPa. The light ends exit D-103 in Stream 82 at 24 kg/min and 175 °C, and are sent to E-207 A/B on Drawing 05-A-018/1 for light end purification. The liquid products From D-103 enter D-104 and are further flashed to 103 kPa. Flash drum 4 removes any remaining light ends in the diesel fuel intermediates. The light ends exit D-104 in Stream 84 at 170 °C and a flow rate of 10 kg/min, and are pressurized to 240 kPa by G-103 A/B before being sent to light end purification shown on Drawing 05-A-018/1in stream 86. The liquid products exit D-104 at 170 °C at a flow rate of 290 kg/min, and are sent to trim purification on Drawing 04-A-018/3 in stream 85.

V.B.4. Trim Purification Section (Drawings 04-A-018/X)

Stream 78 enters the naphtha-jet cut column (D-205) shown on Drawing 04-A-018/3. D-205 separates the naphtha product (C5-C9) from the jet fuel product (C9-C12). D-205 has a height of 28 m, diameter of 1.7 m, 30 trays, and a feed tray of 7. The distillate exits D-205 at 115 °C and 120 kPa. It is then condensed at 38 °C by E-105 A/B, and pressurized to 140 kPa by L-119 A/B. The distillate, Stream 156, is sent to D-311 shown on Drawing 04-A-018/6 at a rate of 64 kg/min, and the reflux is sent back to the column in Stream 157 at a reflux ratio of 1.25. The bottoms exit D-205 at 190 °C and 130 kPa. They are heated to 200 °C by E-403 A/B, and pressurized to 190 kPa by L-120 A/B.

The bottoms in Stream 163 are sent to E-1101 A/B shown on Drawing 04-A-018/6 at a rate of 140 kg/min.

Stream 85 from D-104 shown on Drawing 03-A-018/4 is pressurized to 210 kPa by L-110 A/B on Drawing 04-A-018/3. It is then heated to 200 °C by E-505 A/B. After heating, Stream 167 is sent to the jet diesel cut column (D-204) shown on Drawing 04-A-018/4.

Stream 167 enters D-204 on tray 13. D-204 splits the jet fuel product (C8-C15) from the diesel fuel no. 2 product (C16-C30). D-204 is 24 m tall, 2.6 m in diameter, and has 25 trays. The distillate exits D-204 at 240 °C and 115 kPa. It is then condensed at 41 °C by E-103 A/B, and pressurized to 130 kPa by L-112 A/B. The distillate products leave L-112 A/B in Stream 172 at a rate of 73 kg/min and is sent to E-1101A/B to be cooled further. The reflux is pumped back through the column in Stream 173 at a reflux ratio of 2.7. The bottoms exit the column at 290 °C and 140 kPa, and are heated to 300 °C by E-404 A/B. The bottoms are then pumped to 170 kPa in Stream 178 by L-113 A/B at a flow rate of 200 kg/min. Stream 178 then enters the diesel fuel oil cut column (D-206) shown on Drawing 04-A-018/5.

D-206 (Drawing 04-A-018/5) splits the diesel fuel range intermediates from the bottom fuel oil intermediates. This column is 37 m tall, 2.8 m in diameter, has 40 trays, and a feed to tray 28. The diesel fuel range molecules (C16-C21) exit the top of the column at 340 °C and 150 kPa. They are then cooled to 320 °C by E-107 A/B prior to being pressurized to 170 kPa by L-114 A/B. The reflux is then sent back to the column at a reflux ratio of 0.8, and the diesel fuel intermediates are sent to E-1102 A/B shown on Drawing 04-A-018/7 in Stream 184 at a flow rate of 210 kg/min. The fuel oil intermediates flow out the bottom of the column at 398 °C and 170 kPa. They are then heated in the reboiler (E-409 A/B) to 400 °C. The fuel oil intermediates are sent to E-1103 A/B shown on Drawing 04-A-018/7 in Stream 191 at a flow rate of 4 kg/min after being pressurized to 210 kPa by L-115 A/B.

Stream 156, from D-205 shown on Drawing 04-A-018/2, is combined with Stream 129 from E-407 A/B shown on Drawing 05-A-018/4 in D-311, shown on Drawing 04-A-018/6. They combine to form the naphtha stream product, Stream 193, at 71 °C and 120 kPa. Stream 193 is then pressurized to 170 kPa in Stream 199 at a flow rate of 210 kg/min and sent to storage.

Stream 163 from L-120 A/B on Drawing 04-A-018/2 and Stream 172 from L-112 A/B on Drawing 04-A-018/4 combine to form the jet fuel product stream, Stream 192, on Drawing 04-A-018/6. This stream is cooled to 32 °C by E-1101 A/B, pressurized to 170 kPa by L-118 A/B, Stream 200, and sent to storage at a rate of 210 kg/min.

Stream 184 is routed from L-114 A/B, as shown on Drawing 04-A-018/5, to E-1102003 A/B and cooled to 55 °C. This stream, Stream 201, is then pressurized to 170 kPa by L-129 A/B, and sent to storage as the diesel fuel no. 2 product at a rate of 210 kg/min.

Stream 191 from L-115 A/B on Drawing 04-A-018/5 is cooled to 55 °C by E-1103 A/B on Drawing 04-A-018/7. The stream exiting the fuel oil cooler 1 (E-1103 A/B), Stream 204, is fuel oil no. 5, and is sent to the boiler to serve as fuel at a rate of 4 kg/min.

V.B.5. Light End Processing Section (05-A-018/X)

Stream 82 from D-103 on Drawing 03-A-018/4 is cooled to 38 °C in E-207 A/B shown on Drawing 05-A-018/1 prior to entering flash 5 (D-105). Streams 86 from G-203

A/B and 56 from D-108, shown on Drawings 03-A-018/4 and 02-A-018/3, respectively, combine together and also enters D-105. D-105 separates the naphtha range fuel intermediates (C5-C7) from the light ends (C1-C4). The naphtha range intermediates exit D-105 out the bottom at 21 °C and 103 kPa in Stream 73. Stream 4173 is then sent to D-312 shown on Drawing 03-A-018/3 at 23 kg/min. Stream 92 exits the top of D-105 at 21 °C and 103 kPa, and combines with Stream 4 from D-109 A/B on Drawing 03-A-018/3. The two streams combine to form Stream 93, which is at 36 °C and 103 kPa. Stream 93 flows to G-105, shown on Drawing 05-A-018/2, at 240 kg/min.

Stream 93 enters the light end compressor (G-105) shown on Drawing 05-A-018/2. G-105 is a three stage compressor. The stream is pressurized to 410 kPa and heated to 160 °C in the first stage. It is then cooled by the interstage cooler 1 (E-210 A/B) to 35 °C before entering the second stage of the compressor. The stream is then pressurized to 1520 kPa in stage two, and is also heated to 180 °C. It then flows through the interstage cooler 2 (E-211 A/B), and is cooled to 35 °C before entering the third stage. Stream 105 then exits G-105 at 145 °C and 3170 kPa, and proceeds to the syngas column (D-207), shown on Drawing 05-A-018/3, at 240 kg/min.

Stream 105 is cooled to 32 °C by E-204 A/B, as on shown Drawing 05-A-018/3. It then enters the syngas column (D-207) on tray 5. D-207 is 37 m tall and 2.7 m in diameter with 40 trays. The syngas column removes the syngas (C1-C3) from the butane and naphtha fuel range products. The syngas exits the top of the column at 0 °C and 2700 kPa, and is partially condensed at -20 °C by low temperature refrigerant in E-104 A/B. The syngas product is then sent to the boiler to be used as boiler feed in Stream 110 at 160 kg/min, and the reflux is sent back into the column at a reflux ratio of 0.5. The bottom product exits D-719 at 170 °C and 2790 kPa, and is heated to 180 °C by E-405 A/B. The bottom product is sent to the debutanizer column feed cooler (E-205 A/B) as Stream 115 at a rate of 82 kg/min.

Stream 115 is cooled to 120 °C by E-205 A/B (Drawing 05-A-018/4). This stream then enters D-210 (debutanizer column) on tray 8. D-210 is 11.5 m tall and 2.1 m in diameter, and contains 12 trays. D-210 removes the butane product from the heavier naphtha range products. The butane product exits the top of D-210 at 74 °C and 830 kPa. It is then partially condensed at 70 °C by E-106 A/B. The butane product is then sent to storage in Stream 123 at 21 kg/min. The reflux is sent back to the column at a reflux ratio of 5.3. The bottoms leave D-210 at 130 °C and 850 kPa, and are heated to 150 °C by E-407 A/B. The bottoms product, Stream 129 (64 kg/min), is then combined with Stream 156 on Drawing 04-A-018/6 to produce the Naphtha product which is routed to storage.

V.B.6. Heavy End Processing Section (Drawings 06-A-018/X)

Stream 41 from D-202 shown on Drawing 02-A-018/5 enters E-506 A/B shown on Drawing 06-A-018/1. E-506 A/B heats stream 41 to 410 °C prior to entering the pitching reactor (R-104 A/B). R-104 A/B is 1.2 m in diameter and 3.6 m tall, and sustains a very thin film of vacuum residue under high vacuum (7 kPa) and high temperatures (410 °C). This reactor concentrates the asphaltenes in the pitch by removing as much semi-volatile matter as possible, while promoting condensation reactions in the liquid film due to the high temperature and increased concentration of asphaltenes. The film of vacuum residue falls down the sides of the reactor, and is kept as a thin film due to a rotating scraper which operates at 22 kW [10]. The asphaltene –enriched pitch then exits the bottom of R-104 A/B at 410 °C and 7 kPa in stream 301. Stream 301 then enters J-

101 A/B shown on Drawing 06-A-018/2 at a flow rate of 100 kg/min. The semi-volatile matter exits the top of the reactor in the gas phase in stream 300 at 410 °C and 7 kPa. It is then condensed to 60 °C by E-1104 A/B, and pressurized to 130 kPa by L-130 A/B. Stream 300 then proceeds to the boiler at a flow rate of 180 kg/min.

Stream 301 is fed to the pitch reactor product screw conveyor. J-101 operates at 870 W, and is 6 m long. This conveyor is uninsulated, which allows the mesophse pitch to cool to 120 °C as it is moved along the conveyor. From J-101 A/B, the solids are fed to J-102 A/B, the crusher feed belt conveyor, and are brought 3 m to the mesophase pitch crusher (C-101 A/B). This crusher crushes the solid pitch, and then sends the mesophase pitch product along J-103 A/B at 100 kg/min and 66 °C to storage.

V.C. Economic Assessment

V.C.1. Broad cost Estimate

The capital cost summary for the base design with mesophase pitch recovery is shown in Table 97. This table shows the total capital investment needed to complete the project, and was developed as described in Chapter II. The FCI was found to be $110 million, and the TCI was estimated to be $140 million ± 40%.

V.C.2. Raw Material and Manufacturing Cost Estimate

The raw material cost is based on purchasing crude soybean oil for $0.60/kg (21). The total raw material cost is $300 million per year.

The total manufacturing cost for the base design with mesophase pitch recovery is $14 million per year, and $32 million per year on years the decarboxylate catalyst beds need to be replaced. The manufacturing cost includes chemicals and catalysts costs, operating labor costs, maintenance costs, and utility costs. Table 98 shows the overall yearly operating expense summary for the mesophase pitch recovery design. The plant has an operating factor of 95%. Intermediate results can be found in Appendix C, and communication records can be found in Appendix G.

The catalyst used for the decarboxylation reactors in the mesophase pitch recovery design was a Ni catalyst. The initial charge for the catalyst (shown on the broad cost estimate) covers the total amount of catalyst needed (530,000 kg) for a price of $19 million. This amount is charged every four years in order to recharge the catalyst. It was assumed there was a 4% yearly depletion of the catalyst that needed to be replaced for the years in between. This results in a cost of $750,000 for those years. A quote from Johnson Matthey Catalysts was used for pricing ($28/$m^3$).

The base design with mesophase pitch recovery consists of an equivalent of 26 major unit operations, which equates to 36 new operators to cover continuous operation, as described in Chapter II. An average operator salary of $62,800 was used, and taking into account an additional 15% for supervision, the yearly operating expense equates out to $2,600,000 per year [53]. The maintenance costs were found to be $6.5 million per year.

The utility costs is $4,300,000 per year. This value includes the boiler feed water, cooling water, electricity, refrigeration, process water, and a credit for the leftover syngas. The prices for all the utilities, except the electricity, were priced based off of Turton heuristics. The electricity values were found from typical ND and MN values [57].

V.C.3. Revenues

Revenue for the base design with mesophase pitch recovery comes from the sales of jet fuel, diesel fuel no. 2, petroleum naphtha, butane, mesophase pitch, and acetic acid. Shipping costs were not considered when calculating the amount of revenues generated.

The transportation fuels, jet fuel, diesel fuel no. 2, and petroleum naphtha, produce a revenue of $140 million/year. This value was based on the production 120,000 liquid m3/year of petroleum naphtha that can be sold for $0.36/L, jet fuel at a rate of 170,000 liquid m3/year which is sold for $0.37/L, and diesel fuel no. 2 produced at 170,000 liquid m3/year and sold at $0.37/L. The remaining by products produce a revenue of $520 million/year. Of this $520 million, $510 million/year is from the sale of mesophase pitch. The total annual revenue for the base design is $660 million/year.

V.C.4. Overall Profitability

The cash flow sheet for the base design with mesophase pitch recovery is shown in Table 99. The process has a NPV@12% of $1.4 billion ± 40%. The project produces a gross income of $340 million per year, and has a DCFROR value of 104%. The positive NPV@12% value and a DCFROR value greater than 12% show that the investment is profitable over the project lifecycle.

V.D. Break Even Point

With the current design and prices of products and raw materials, the process recovers the initial investment within the first year. In order for the process to break even over the 20 year lifecycle, the price of soybean oil would have to rise to a price of $1.23/kg, which last happened in August, 2013. The cash flow sheet based on this raw material price is shown in Table 100.

The process would also have the potential to only break even if the prices of the products lower significantly. The major revenue producer for this process is the byproduct of mesophase pitch. This byproduct is estimated to be currently sold for \$10.50/kg, which is discounted 30% from the quoted value for high quality carbon fibers of \$15.00/kg. This price is discounted to account for the processing of the pitch into carbon fibers. If this price dropped to \$4.08/kg the process would break even over the 20 year life cycle. The cash flow sheet with the sale price of \$4.08/kg for mesophase pitch can be found in Table 101.

In addition, mesophase pitch has the potential to be sold for up to \$21.00/kg. If the price of pitch were to rise to this high end value the plant has the potential to product a NPV@12% of \$3.6 billion ± 40% over the 20 year life cycle. The case flow sheet for this product price can be found in Table 102.

A more in depth economic analysis surround the TAG oil biorefinery is given in Chapter VI and VII. Chapter VI performs an analysis with crop oil integration while Chapter VII performs a hazard analysis on the margin between the transportation fuel products and raw material cost.

Table 71. Soybean oil composition.

Component	Weight %
Linolenic Acid	12%
Linoleic Acid	51%
Oleic Acid	23%
Stearic Acid	4%
Palmitic Acid	10%

Table 72. Raw materials list for base design with mesophase pitch recovery.

Raw Material	Amount
Soybean Oil	600,000 m^3/year

Table 73. Transportation fuel products from base design with mesophase pitch recovery.

Product	Amount (liquid m^3/year)
Petroleum Naphtha	120,000
Jet Fuel	170,000
Diesel Fuel No. 2	170,000

Table 74. Petroleum naphtha product properties from base design with mesophase pitch recovery.

Specification	Measurement
Density at 15 °C	696 kg/m3
Total paraffins volume %	67%
Olefins volume %	1%
Aromatics volume %	16%
Initial boiling point	50 °C
Temperature at 5% recovered	52 °C
Temperature at 10% recovered	56 °C
Temperature at 20% recovered	63 °C
Temperature at 30% recovered	75 °C
Temperature at 40% recovered	77 °C
Temperature at 50% recovered	88 °C
Temperature at 60% recovered	95 °C
Temperature at 70% recovered	98 °C
Temperature at 80% recovered	113 °C
Temperature at 90% recovered	118 °C
Final boiling point	129 °C
Reid vapor pressure at 37.8 °C	117 kPa

Table 75. Jet fuel product properties from base design with mesophase pitch recovery.

Specification	Measurement
Aromatics volume %	14 %
Temperature at 10% recovered	165 °C
Temperature at 50% recovered	202 °C
Temperature at 90% recovered	252 °C
Final boiling point	270 °C
Flash point	46 °C
Density at 15 °C	772 kg/m3
Freezing point	-46.1 °C
Viscosity at -20 °C,	3.0 mm2/s
Net heat of combustion	43.6 MJ/kg
Smoke point	26.83 mm
Cetane number	58.5

Table 76. Diesel fuel no. 2 product properties from base design with mesophase pitch recovery.

Specification	Measurement
Flash point	118 °C
Water volume %	0%
Temperature at 90% recovered	334 °C
Kinematic viscosity at 40 °C	3.35 mm2/s
Cetane number	79.5
Aromaticity volume %	15 %
Cloud point	3.8 °C

Table 77. Byproduct production in base design with mesophase pitch recovery.

Product	Amount
Butane	21,000 liquid m^3/year
Acetic Acid	2,900 liquid m^3/year
Mesophase Pitch	49,000,000 Mkg/year

Table 78. Butane product properties from base design with mesophase pitch recovery.

Specification	Measurement
Vapor pressure at 37.8 °C	397 kPa
Temperature at 95% recovered	2.2 °C
Pentane and heavier volume %	2.0 %
Relative density at 15.6/15.6°C	0.58
Free water content	0

Table 79. Boiler fuel products produced in base design with mesophase pitch recovery.

Fuel	Amount
Syngas	15,000,000 Nm^3 gas/year
Fuel Oil No. 5	1,200,000 liquid m^3/year

Table 80. Initial charge of catalyst required for base design with mesophase pitch recovery.

Catalyst	**Amount**
Ni/SiO_2 Catalyst	530,000 kg

Table 81. Utility requirements for base design with mesophase pitch recovery.

Utility	**Amount**
Boiler Feed Water	5,600,000,000 kg/year
Cooling Water	54,000 m^3/year
Electricity	18,300,000 kW
Refrigeration (Low Temp)	280,000,000 kg/year
Process Steam	8,200,000 kg/year

Table 82. Equipment lettering system [47].

Letter	Definition
C	Crushers
D	Process (Pressure) Vessels
E	Heat Exchangers
F	Storage Vessels
G	Gas Movers
J	Solid Conveyors
L	Pumps
P	Package Units
Q	Furnaces
R	Reactors

Table 83. Equipment number codes and corresponding definitions for base design with mesophase pitch recovery.

Code	Definition
C-100 Series	Crushers
D-100 Series	Flash Drums
D-200 Series	Distillation Columns
D-300 Series	Reflux Drums
E-100 Series	Column Condensers
E-200 Series	Cooler Heat Exchangers
E-400 Series	Column Reboilers
E-500 Series	Heater Heat Exchangers
E-1100 Series	Product Coolers
D-500 Series	Knockout Drums
G-100 Series	Compressors
J-100 Series	Solid Conveyors
L-100 Series	Pumps
P-100 Series	Refrigeration Unit
Q-100 Series	Boilers
R-100 Series	Reactors
1##	Unit Number
A	Equipment 1 for redundant equipment
B	Equipment 2 for redundant equipment

Table 84. Equipment naming system using example number D-601 A.

Code	D	100 Series	101	A
Definition	Pressure Vessels	Flash Drum	First Unit	Equipment piece 1 of 2

Table 85. Crusher equipment list.

Equipment ID	Equipment Name/Description	Power Requirement (W)	Design Flow Rate (kg/min)	Temperature (°C)	MOC
C-101 A/B	Mesophase Pitch Crusher	870	100	120	Carbon Steel

Table 86. Flash drum equipment list.

Equipment ID	Equipment Name/Description	Height (m)	Diameter (m)	Orientation	Pressure (kPa) Design Basis	Temperature (°C)	MOC
D-101	Flash 1	5.8	1.4	Vertical	690	210	Stainless Steel Clad
D-102	Flash 2	5.3	1.4	Vertical	140	150	Stainless Steel Clad
D-103	Flash 3	4.9	1.2	Vertical	1720	175	Carbon Steel
D-104	Flash 4	4.7	1.2	Vertical	103	170	Carbon Steel
D-105	Flash 5	5.4	1.4	Vertical	103	21	Carbon Steel
D-107	Acetic Flash 1	1.8	0.5	Horizontal	1380	215	Stainless Steel Clad
D-108	Acetic Flash 2	3.4	0.8	Horizontal	210	65	Stainless Steel Clad
D-109	Flash 7	2.7	0.7	Vertical	103	77	Carbon Steel

Table 87. Distillation column equipment list.

Equipment ID	Equipment Name/Description	Height (m)	Diameter (m)	Trays*	Feed Tray	Pressure (kPa)	Temperature (°C)	MOC: Body	MOC: Trays
D-201	Atmospheric Column	8.4	2.4	7	3	130	280	ss clad	ss
D-202	Vacuum Colum	20	2.9	20	5	28	330	ss clad	ss
D-204	Jet Diesel Cut	24	2.6	25	13	130	300	cs	ss
D-205	Naphtha-Jet Cut	28	1.7	30	7	130	200	cs	ss
D-206	Diesel-Fuel Oil Cut	37	2.8	40	28	140	530	cs	ss
D-207	Syngas Column	37	2.7	40	5	2750	180	cs	ss
D-210	Debutanizer	11.5	2.1	12	8	830	145	cs	ss

*Based on sieve tray at 80% efficiency

Table 88. Reflux drum equipment list.

Equipment ID	Equipment Name/Description	Volume (m3)	Orientation	Length (m)	Diameter (m)	Temperature (°C)	Pressure (kPa)	Flow Rate (m3/min)	MOC
D-301	Atmospheric Column Reflux Drum	1.4	Horizontal	3	0.8	60	110	0.3	ss clad
D-302	Vacuum Column Reflux Drum	8.1	Horizontal	5.5	1.4	230	14	1.2	ss clad
D-304	Jet-Diesel Cut Reflux Drum	1.4	Horizontal	3	0.8	41	103	0.3	cs
D-305	Naphtha-Jet Cut Reflux Drum	1.4	Horizontal	3	0.8	38	110	0.2	cs
D-306	Diesel-Fuel Oil Cut Reflux Drum	3.8	Horizontal	4.3	1.1	320	110	0.7	cs
D-307	Syngas Column Reflux Drum	3.8	Horizontal	4.3	1.1	-20	2690	0.3	cs
D-308	Debutanizer Reflux Drum	2.4	Horizontal	3.7	0.9	70	810	0.2	cs
D-310	Acetic Acid Drum	0.1	Horizontal	1.2	0.3	93	210	0.01	ss clad
D-311	Naphtha Drum	2.4	Horizontal	3.7	0.9	71	120	0.4	cs
D-312	Flash 7 Drum	3.8	Horizontal	3.2	1.1	71	103	0.7	ss clad

Table 89. Knockout drum equipment list.

Equipment ID	Equipment Name/Description	Volume (m3)	Orientation	Length (m)	Diameter (m)	Temperature (°C)	Pressure (kPa)	Flow Rate (m3/min)	MOC
D-505 A/B	Stage 1 Light End Knockout Drum	4	Horizontal	3.6	1.2	36	103	140	cs
D-506 A/B	Stage 2 Light End Knockout Drum	0.6	Horizontal	1.9	0.6	35	400	41	cs
D-507 A/B	Stage 3 Light End Knockout Drum	0.1	Horizontal	1	0.3	35	1500	11	cs

Table 90. Heat exchanger equipment list.

Equipment ID	Equipment Name/Description	Area (m3)	Duty (kW)	Tube Inlet Temp (°C)	Tube Outlet Temp (°C)	Tube Pressure (kPa)	Tube MOC	Tube Fluid	Shell Inlet Temp (°C)	Shell Outlet Temp (°C)	Shell Pressure (kPa)	Shell MOC	Shell Fluid	Heat Transfer Coefficient (W/m2-°C)
E-101 A/B	Atmospheric Column Condenser	660	2500	210	60	124	ss	C7-C12 fuel intermediates	55	200	4550	cs	Boiler Feed Water	850
E-102 A/B	Vacuum Column Condenser	55	5500	315	230	21	ss	C12-C30 fuel intermediates	55	239	4550	cs	Medium Pressure Steam	850
E-103 A/B	Jet Diesel Cut Condenser	340	2900	240	41	115	ss	C8-C15 fuel intermediates	30	200	4550	cs	Boiler Feed Water	425
E-104 A/B	Syngas Condenser	75	580	0	-20	2700	cs	Syngas	-30	-23	380	cs	Refrigerant	510
E-105 A/B	Naphtha Jet Condenser	500	1600	115	38	120	cs	C7-C9 fuel intermediates	30	93	380	cs	Cooling Water	450
E-106 A/B	Debutanizer Condenser	44	760	74	70	830	cs	Butane Product	30	140	55	cs	Cooling Water	510
E-107 A/B	Diesel-Fuel Oil Cut Condenser	15	2200	340	320	150	cs	C12-C21 fuel intermediates	55	240	3340	cs	Medium Pressure Steam	850
E-201 A/B	Cracking Cross Exchanger	320	14000	430	230	1800	ss	C1-C50 Crackate	20	310	140	cs	Soybean Oil	280
E-202 A/B	Flash 2 Cooler	170	2700	210	150	690	ss	C7-C50 fuel intermediates	55	205	4550	cs	Boiler Feed Water	425
E-204 A/B	Light End Cooler	360	1400	145	32	3170	cs	C1-C6 fuel intermediates	30	120	4550	cs	Boiler Feed Water	425
E-205 A/B	Debutanizer Cooler	16	340	180	120	2760	cs	C4-C6 fuel intermediates	55	150	4550	cs	Boiler Feed Water	425
E-207 A/B	Pre-Flash 5 Cooler	41	400	180	38	1720	ss	Syngas	30	45	380	cs	Cooling Water	510
E-208 A/B	Post Diesel Decarbox Cooler	33	2800	320	180	2200	cs	C1-C30 fuel intermediates	55	240	4500	cs	Medium Pressure Steam	850
E-209 A/B	Post Naphtha Decarbox Cooler	74	3600	320	93	2200	cs	C1-C12 fuel intermediates	55	240	4550	cs	Medium Pressure Steam	850
E-210 A/B	Interstage Cooler 1	210	750	160	35	410	ss	C1-C6 fuel intermediates	30	150	4550	cs	Boiler Feed Water	450
E-211 A/B	Interstage Cooler 2	130	890	180	35	1520	ss	C1-C6 fuel intermediates	30	150	4550	cs	Boiler Feed Water	450
E-401 A/B	Atmospheric Column Reboiler	200	7300	400	330	4500	ss	High Pressure Steam	280	310	140	ss clad	C7-C50 fuel intermediates	540
E-402 A/B	Vacuum Column Reboiler	840	4300	400	330	4500	ss	High Pressure Steam	330	340	140	ss clad	Heavy Ends	340
E-403 A/B	Naphtha Jet Cut Reboiler	100	2400	240	240	3300	ss	Medium Pressure Steam	190	200	130	cs	C9-C12 fuel intermediates	540
E-404 A/B	Jet Diesel Cut Reboiler	170	3500	400	330	4500	ss	High Pressure Steam	290	300	140	cs	C16-C30 fuel intermediates	340

(continued)

Table 90. Cont.

Equipment ID	Equipment Name/Description	Area (m3)	Duty (kW)	Tube Inlet Temp (°C)	Tube Outlet Temp (°C)	Tube Pressure (kPa)	Tube MOC	Tube Fluid	Shell Inlet Temp (°C)	Shell Outlet Temp (°C)	Shell Pressure (kPa)	Shell MOC	Shell Fluid	Heat Transfer Coefficient (W/m2-°C)
E-405 A/B	Syngas Column Reboiler	19	1000	240	240	3300	ss	Medium Pressure Steam	170	180	2790	cs	C4-C6 fuel intermediates	850
E-407 A/B	Debutanizer Reboiler	11	900	240	240	3300	ss	Medium Pressure Steam	130	150	850	cs	C5-C6 fuel intermediates	850
E-409 A/B	Diesel Fuel Oil Cut Reboiler	200	2200	435	370	6000	ss	Superheated Steam	398	400	170	cs	C22-C30 fuel intermediates	450
E-502 A/B	TTCT Preheat	460	6300	435	370	6000	ss	Superheated Steam	310	410	1930	ss clad	Soybean Oil	340
E-503 A/B	Naphtha Decarbox Heater	43	3700	400	330	4500	ss	High Pressure Steam	60	320	2400	cs	C6-C12 fuel intermediates	540
E-504 A/B	Diesel Decarbox Heater	41	1800	400	330	4500	ss	High Pressure Steam	230	320	2400	cs	C12-C30 fuel intermediates	480
E-505 A/B	Pre Jet Diesel Cut Heat	22	540	240	240	3300	cs	Medium Pressure Steam	170	200	210	cs	C8-C30 fuel intermediates	480
E-506 A/B	Pitching Preheat	120	2400	340	410	140	ss	Heavy Ends	435	370	6000	ss clad	Superheated Steam	450
E-1101 A/B	Jet Cooler	260	1200	150	32	130	cs	Jet Fuel Product	30	120	3170	cs	Boiler Feed Water	425
E-1102 A/B	Diesel Cooler	130	3000	320	55	170	cs	Diesel Fuel No. 2 Product	50	240	3340	cs	Medium Pressure Steam	850
E-1103 A/B	Fuel Oil Cooler 1	6	80	400	55	210	cs	Fuel Oil No. 5	50	240	3340	cs	Medium Pressure Steam	280
E-1104 A/B	Fuel Oil Cooler 2	690	4400	410	60	7	ss	Fuel Oil No. 5	55	400	4650	cs	High Pressure Steam	850

Table 91. Compressor equipment list.

Equipment ID	Equipment Name/Description	Stages	Inlet Pressure (kPa)	Outlet Pressure (kPa)	Inlet Temp (°C)	Outlet Temp (°C)	Flow Rate (m3/min)	Power (kW)	MOC	Fluid
G-101 A/B	Flash 2 Compressor	1	140	410	150	200	3.4	17	ss	C1-C8 fuel intermediates
G-103 A/B	Flash 5 Compressor	1	103	240	170	220	5.5	15	cs	C3-C7 fuel intermediates
G-105 Stage 1	Light End Compressor	3	103	410	36	160	140	630	cs	C1-C6 fuel intermediates
G-105 Stage 2	Light End Compressor	3	400	1520	35	180	40	630	cs	C1-C6 fuel intermediates
G-105 Stage 3	Light End Compressor	3	1500	3170	35	145	11	630	cs	C1-C6 fuel intermediates

Table 92. Pump equipment list.

Equipment ID	Equipment Name/Description	Power (kW)	Inlet Pressure (kPa)	Outlet Pressure (kPa)	Temperature (°C)	Fluid	MOC
L-101 A/B	PreCracking Pump	70	103	1930	310	Soybean Oil	ss
L-103 A/B	Pre Naphtha Decarbox	17	140	2400	60	C6-C12 fuel intermediates	ss
L-104 A/B	Atmospheric Reflux	1.6	90	140	60	C7-C12 fuel intermediates	ss
L-105 A/B	Atmospheric Bottoms	0.81	103	140	310	C13-C50 fuel intermediates	ss
L-106 A/B	Vacuum Column Bottom	4	35	140	330	Heavy Ends	ss
L-107 A/B	Vacuum Bottoms	0.76	103	140	340	Heavy Ends	ss
L-108 A/B	Vacuum Reflux	5	7	140	230	C12-C30 fuel intermediates	ss
L-109 A/B	PreDiesel Decarbox	29	140	2400	230	C12-C30 fuel intermediates	ss
L-110 A/B	PreJet-Diesel Cut Heat Pump	1	103	210	170	C8-C30 fuel intermediates	scs
L-111 A/B	Naphtha Product	0.2	120	170	71	Naphtha Product	cs
L-112 A/B	Jet Diesel Cut Reflux	4	83	130	41	C8-C15 fuel intermediates	cs
L-113 A/B	Jet Diesel Cut Bottoms	0.53	103	170	300	C16-C30 fuel intermediates	cs
L-114 A/B	Diesel Fuel Oil Cut Reflux	7	110	170	320	C16-C21 fuel intermediates	ss
L-115 A/B	Diesel Fuel Oil Cut Bottoms	0.03	140	210	400	C22-C30 fuel intermediates	ss
L-116 A/B	Flash 5 Pump	0.05	140	170	21	C6-C9 fuel intermediates	ss
L-118 A/B	Jet Fuel Product	0.54	103	170	32	Jet Fuel Product	cs

(continued)

Table 92. Cont.

Equipment ID	Equipment Name/Description	Power (kW)	Inlet Pressure (kPa)	Outlet Pressure (kPa)	Temperature (°C)	Fluid	MOC
L-119 A/B	Naphtha Jet Reflux	5	90	140	38	C7-C9 fuel intermediates	Cs
L-120 A/B	Naphtha Jet Bottoms	0.51	95	190	200	C9-C12 fuel intermediates	cs
L-121 A/ B	Debutanizer reflux	2	790	835	70	Butane	cs
L-127 A/B	Syngas Reflux	6	2675	2720	-20	Syngas	cs
L-128 A/B	Flash 7 Pump	0.25	103	140	71	C6-C9 fuel intermediates	cs
L-129 A/B	Diesel Product	0.33	140	170	55	Diesel Fuel No. 2 Product	cs
L-130 A/B	Fuel Oil Pump	1	5	140	60	Fuel Oil No. 5	cs

Table 93. Reactor equipment list.

Equipment ID	Equipment Name/Description	Diameter (m)	Length (m)	Tubes	Catalyst (m3)	Power (kW)	Residence Time (hr)	Temperature (°C)	Pressure (kPa)	MOC
R-101	TTCR	6.1	12.2	10300	N/A	N/A	1.17	430	1800	cs/inconel
R-102 A/B	Naphtha Decarboxylation Reactor	2.9	17	N/A	220	N/A	3.2	320	2200	ss clad
R-103 A/B	Diesel Decarboxylation Reactor	3.2	19	N/A	310	N/A	4.8	320	2200	ss clad
R-104 A/B	Pitching Reactor	1.2	3.6	N/A	N/A		0.25	410	7	ss clad

Table 94. Conveyor equipment list.

Equipment ID	Equipment Name/Description	Width (m)	Length (m)	Design Flow Rate (kg/min)	Power (kW)
J-101 A/B	Pitch Reactor Product Screw Conveyor	1.5	6	100	0.87
J-102 A/B	Crusher Feed Belt Conveyor	1.5	3	100	0.43
J-103 A/B	Mesophase Pitch Belt Conveyor	1.5	150	100	16

Table 95. Drawing number codes and corresponding definitions for the base design with mesophase pitch recovery.

Code	**Definition**
00	Entire Plant
01	Thermal Cracking Section
02	Purification Section
03	Decarboxylation Section
04	Trim Purification Section
05	Light End Processing
06	Heavy End Processing
A	11x17" Drawing Size
016	Mesophase Pitch Recovery Input/Output Diagram - Metric Units
017	Mesophase Pitch Recovery Design Block Flow Diagram - Metric Units
018	Mesophase Pitch Recovery Design Process Flow Diagram - Metric Units

Table 96. Drawing naming system using example number 00-A-001/1.

Code	00	A	001	/1
Definition	Plant Section	Drawing Size	Drawing Type	Sheet

Table 97. Broad cost estimate for base design with mesophase pitch recovery.

Equipment	Equipment Description	Number	Capacity/Size Specs	Purchased Equipment Cost: Basis Date: Year 2004	Purchased Equipment Cost: Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
C-101 A/B	Mesophase Pitch Crusher	2	Capacity : 100 kg/min Power: 1.3 kW MOC: Carbon Steel	$10,000	$13,000	1	1	2.1	$28,000	$56,000
D-101	Flash 1	1	Height: 5.8 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$11,750	$16,000	2.5	1	7	$110,000	$110,000
D-102	Flash 2	1	Height: 5.3 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$11,500	$15,000	2.5	1	7	$110,000	$110,000
D-103	Flash 3	1	Height: 4.9 m Inside Diameter: 1.2m Vertical Orientation MOC: Carbon Steel	$11,000	$15,000	1	2	6	$89,000	$89,000
D-104	Flash 4	1	Height: 4.7 m Inside Diameter: 1.2 m Vertical Orientation MOC: Carbon Steel	$11,000	$15,000	1	1	4	$59,000	$59,000
D-105	Flash 5	1	Height: 5.4 m Inside Diameter: 1.4 m Vertical Orientation MOC: Carbon Steel	$10,000	$13,000	1	1	4	$54,000	$54,000
D-107	Acetic Flash 1	1	Length: 1.8 m Inside Diameter: 0.5 m Horizontal Orientation MOC: Stainless Steel Clad	$1,500	$2,000	2.5	1.5	8	$16,000	$16,000

(continued)

Table 97. Broad cost estimate for base design with mesophase pitch recovery cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-108	Acetic Flash 2	1	Length: 3.4 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$5,000	$6,700	2.5	1	7	$47,000	$47,000
D-109	Flash 7	1	Height: 2.7 m Inside Diameter: 0.7 m Vertical Orientation MOC: Carbon Steel	$3,000	$4,000	1	1	4	$16,000	$16,000
D-201	Atmospheric Column	1	Height: 8.4 m Diameter: 2.4 m Trays: 7 Feed: Tray 3 MOC: Stainless Steel Clad	$40,000	$54,000	2.5	1	7	$380,000	$380,000
D-201 Trays	Atmospheric Column Trays	7	Diameter: 2.4 m MOC: Stainless Steel	From Quote	$2,500	1	1	1.2	$3,000	$21,000
D-202	Vacuum Colum	1	Height: 20 m Diameter: 2.9 m Trays: 20 Feed: Tray 5 MOC: Stainless Steel Clad	$70,000	$94,000	2.5	1	7	$660,000	$660,000
D-202 Trays	Vacuum Column Trays	20	Diameter: 2.9 m MOC: Stainless Steel	From Quote	$2,800	1	1	1.2	$2,800	$56,000
D-204	Jet Diesel Cut	1	Height: 24 m Diameter: 2.6 m Trays: 25 Feed: Tray 13 MOC: Carbon Steel	$50,000	$67,000	1	1	4	$270,000	$270,000
D-204 Trays	Jet Diesel Cut Trays	25	Diameter: 2.6 m MOC: Stainless Steel	From Quote	$2,600	1	1.025	1.2	$3,200	$81,000
D-205	Naphtha-Jet Cut	1	Height: 27.5 m Diameter: 1.7 m Trays: 30 Feed: Tray 7 MOC: Carbon Steel	$80,000	$110,000	1	1	4	$430,000	$430,000

(continued)

Table 97. Broad cost estimate for base design with mesophase pitch recovery cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-205 Trays	Naphtha-Jet Cut Trays	30	Diameter: 1.7 m MOC: Stainless Steel	From Quote	$2,100	1	1	1.2	$2,500	$76,000
D-206	Diesel-Fuel Oil Cut	1	Height: 37 m Diameter: 2.8 m Trays: 40 Feed: Tray 28 MOC: Carbon Steel	$150,000	$200,000	1	1	4	$810,000	$810,000
D-206 Trays	Diesel-Fuel Oil Cut Trays	40	Diameter: 2.8 m MOC: Stainless Steel	From Quote	$2,800	1	1	1.2	$3,300	$130,000
D-207	Syngas Column	1	Height: 37 m Diameter: 2.7 m Trays: 40 Feed: Tray 5 MOC: Carbon Steel	$125,000	$170,000	1	3	8	$1,300,000	$1,300,000
D-207 Trays	Syngas Trays	40	Diameter: 2.7 m MOC: Stainless Steel	From Quote	$2,700	1	1	1.2	$3,300	$130,000
D-210	Debutanizer	1	Height: 11.5 m Diameter: 2.1 m Trays: 12 Feed: Tray 8 MOC: Carbon Steel	$45,000	$60,000	1	2	6	$360,000	$360,000
D-210 Trays	Debutanizer Trays	12	Diameter: 2.1 m MOC: Stainless Steel	From Quote	$2,300	1	1.18	1.2	$3,300	$40,000
D-301	Atmospheric Column Reflux Drum	1	Length: 3 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$4,000	$5,400	2.5	1	4	$21,000	$21,000
D-302	Vacuum Column Reflux Drum	1	Length: 5.5 m Inside Diameter: 1.4 m Horizontal Orientation MOC: Stainless Steel Clad	7000	$9,400	2.5	1	4	$38,000	$38,000

(continued)

Table 97. Broad cost estimate for base design with mesophase pitch recovery cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-304	Jet-Diesel Cut Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	$4,000	$5,400	1	1	3	$16,000	$16,000
D-305	Naphtha-Jet Cut Reflux Drum	1	Length: 3 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	4000	$5,400	1	1	3	$16,000	$16,000
D-306	Diesel-Fuel Oil Cut Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	$6,000	$8,100	1	1	3	$24,000	$24,000
D-307	Syngas Column Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	6000	$8,100	1	1	3	$24,000	$24,000
D-308	Debutanizer Reflux Drum	1	Length: 3.7 m Inside Diameter: 0.9 m Horizontal Orientation MOC: Carbon Steel	$5,500	$7,400	1	1	3	$22,000	$22,000
D-310	Acetic Acid Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Stainless Steel Clad	2500	$3,400	2.5	1	4	$13,000	$13,000
D-311	Naphtha Drum	1	Length: 3.7 m Inside Diameter: 0.9 m Horizontal Orientation MOC: Carbon Steel	$5,500	$7,400	1	1	3	$22,000	$22,000
D-312	Flash 7 Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Stainless Steel Clad	6000	$8,100	2.5	1	4	$32,000	$32,000
D-505 A/B	Stage 1 Light End Knockout Drum	2	Height: 3.6 m Inside Diameter: 1.2 m Horizontal Orientation MOC: Carbon Steel	$10,000	$13,000	1	1	4	$54,000	$110,000

(continued)

Table 97. Broad cost estimate for base design with mesophase pitch recovery cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-506 A/B	Stage 2 Light End Knockout Drum	2	Height: 1.9 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Carbon Steel	4000	$5,400	1	1	4	$21,000	$43,000
D-507 A/B	Stage 3 Light End Knockout Drum	2	Height: 1.0 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Carbon Steel	$2,000	$2,700	1	1	4	$11,000	$21,000
E-101 A/B	Atmospheric Column Condenser	2	Surface Area: 660 m2 Heat Duty: 2500 kW MOC (shell/tube): cs/ss	55000	$74,000	1.7	1	4	$130,000	$250,000
E-102 A/B	Vacuum Column Condenser	2	Surface Area: 55 m2 Heat Duty: 5500 kW MOC (shell/tube): cs/ss	$11,000	$15,000	1.7	1	4	$59,000	$120,000
E-103 A/B	Jet Diesel Cut Condenser	2	Surface Area: 340 m2 Heat Duty: 2900 kW MOC (shell/tube): cs/ss	32000	$43,000	1.7	1	4	$170,000	$340,000
E-104 A/B	Syngas Condenser	2	Surface Area: 75 m2 Heat Duty: 580 kW MOC (shell/tube): cs/cs	$12,000	$16,000	1	1	3.2	$52,000	$100,000
E-105 A/B	Naphtha Jet Condenser	2	Surface Area: 500 m2 Heat Duty: 1600 kW MOC (shell/tube): cs/cs	45000	$60,000	1	1.1	3.2	$190,000	$390,000
E-106 A/B	Debutanizer Condenser	2	Surface Area: 44 m2 Heat Duty: 760 kW MOC (shell/tube): cs/cs	$9,500	$13,000	1	1	3.2	$41,000	$82,000
E-107 A/B	Diesel-Fuel Oil Cut Condenser	2	Surface Area: 15 m2 Heat Duty: 2200 kW MOC (shell/tube): cs/cs	4000	$5,400	1	1	3.2	$17,000	$34,000
E-201 A/B	Cracking Cross Exchanger	2	Surface Area: 320 m2 Heat Duty: 14,000 kW MOC (shell/tube): cs/ss	$30,000	$40,000	1.7	1	4	$160,000	$320,000

(continued)

Table 97. Broad cost estimate for base design with mesophase pitch recovery cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-202 A/B	Flash 2 Cooler	2	Surface Area: 170 m2 Heat Duty: 2700 kW MOC (shell/tube): cs/ss	15000	$20,000	1.7	1.25	4	$81,000	$160,000
E-204 A/B	Light End Cooler	2	Surface Area: 360 m2 Heat Duty: 1400 kW MOC (shell/tube): cs/cs	$35,000	$47,000	1	1.1	3.25	$150,000	$310,000
E-205 A/B	Debutanizer Cooler	2	Surface Area: 16 m2 Heat Duty: 340 kW MOC (shell/tube): cs/cs	4000	$5,400	1	1	3.2	$17,000	$34,000
E-207 A/B	Pre-Flash 5 Cooler	2	Surface Area: 41 m2 Heat Duty: 400 kW MOC (shell/tube): cs/ss	$9,500	$13,000	1.7	1	4	$51,000	$100,000
E-208 A/B	Post Diesel Decarbox Cooler	2	Surface Area: 33 m2 Heat Duty: 2800 kW MOC (shell/tube): cs/cs	$8,000	$11,000	1	1	3.2	$34,000	$69,000
E-209 A/B	Post Naphtha Decarbox Cooler	2	Surface Area: 74 m2 Heat Duty: 3600 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3.2	$43,000	$86,000
E-210 A/B	Interstage Cooler 1	2	Surface Area: 210 m2 Heat Duty: 750 kW MOC (shell/tube): cs/ss	$22,500	$30,000	1.7	1	4	$120,000	$240,000
E-211 A/B	Interstage Cooler 2	2	Surface Area: 130 m2 Heat Duty: 890 kW MOC (shell/tube): cs/ss	$14,000	$19,000	1.7	1	4	$75,000	$150,000
E-401 A/B	Atmospheric Column Reboiler	2	Surface Area: 200 m2 Heat Duty: 7300 kW MOC (shell/tube): ss clad/ss	$22,500	$30,000	3	1.1	6	$180,000	$360,000
E-402 A/B	Vacuum Column Reboiler	2	Surface Area: 840 m2 Heat Duty: 4300 kW MOC (shell/tube): ss clad/ss	$60,000	$81,000	3	1.1	6	$480,000	$970,000

(continued)

Table 97. Broad cost estimate for base design with mesophase pitch recovery cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-403 A/B	Naphtha Jet Cut Reboiler	2	Surface Area: 100 m2 Heat Duty: 2400 kW MOC (shell/tube): cs/ss	$12,000	$16,000	1.7	1	4	$64,000	$130,000
E-404 A/B	Jet Diesel Cut Reboiler	2	Surface Area: 170 m2 Heat Duty: 3500 kW MOC (shell/tube): cs/ss	$20,000	$27,000	1.7	1.1	4.5	$120,000	$240,000
E-405 A/B	Syngas Column Reboiler	2	Surface Area: 19 m2 Heat Duty: 1000 kW MOC (shell/tube): cs/ss	$8,000	$11,000	1.7	1.1	4.5	$48,000	$97,000
E-407 A/B	Debutanizer Reboiler	2	Surface Area: 11 m2 Heat Duty: 900 kW MOC (shell/tube): cs/ss	$4,000	$5,400	1.7	1.1	4.5	$24,000	$48,000
E-409 A/B	Diesel Fuel Oil Cut Reboiler	2	Surface Area: 200 m2 Heat Duty: 2200 kW MOC (shell/tube): cs/ss	$25,000	$34,000	1.7	1.1	4.5	$150,000	$300,000
E-502 A/B	TTCT Preheat	2	Surface Area: 460 m2 Heat Duty: 6300 kW MOC (shell/tube): ss clad /ss	$40,000	$54,000	3	1.25	7	$380,000	$750,000
E-503 A/B	Naphtha Decarbox Heater	2	Surface Area: 43 m2 Heat Duty: 3700 kW MOC (shell/tube): cs/ss	$10,000	$13,000	1.7	1.1	4.5	$60,000	$120,000
E-504 A/B	Diesel Decarbox Heater	2	Surface Area: 41 m2 Heat Duty: 1800 kW MOC (shell/tube): cs/ss	$10,000	$13,000	1.7	1.1	4.5	$60,000	$120,000
E-505 A/B	Pre Jet Diesel Cut Heat	2	Surface Area: 22 m2 Heat Duty: 540 kW MOC (shell/tube): cs/cs	$6,000	$8,100	1	1	3.2	$26,000	$52,000
E-506 A/B	Pitching Preheat	2	Surface Area: 120 m2 Heat Duty: 2400 kW MOC (shell/tube): ss clad/ss	$13,500	$18,000	3	1.25	7	$130,000	$250,000

(continued)

Table 97. Broad cost estimate for base design with mesphase pitch recovery cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-1101 A/B	Jet Cooler	2	Surface Area: 260 m2 Heat Duty: 1200 kW MOC (shell/tube): cs/cs	$27,500	$37,000	1	1	3.2	$120,000	$240,000
E-1102 A/B	Diesel Cooler	2	Surface Area: 130 m2 Heat Duty: 3000 kW MOC (shell/tube): cs/cs	$14,000	$19,000	1	1	3.2	$60,000	$120,000
E-1103 A/B	Fuel Oil Cooler 1	2	Surface Area: 6 m2 Heat Duty: 80 kW MOC (shell/tube): cs/cs	$3,000	$4,000	1	1	3.2	$13,000	$26,000
E-1104 A/B	Fuel Oil Cooler 2	2	Surface Area: 690 m2 Heat Duty: 4400 kW MOC (shell/tube): cs/ss	$50,000	$67,000	1.7	1.1	4.5	$300,000	$600,000
G-101 A/B	Flash 2 Compressor	2	Power: 17 kW Number of Stages: 1 MOC: Stainless Steel	From Quote	$18,000	1	1	2.52	$46,000	$91,000
G-103 A/B	Flash 5 Compressor	2	Power: 15 kW Number of Stages: 1 MOC: Carbon Steel	From Quote	$16,000	1	1	2.5	$41,000	$81,000
G-105	Light End Compressor	1	Power: 1900 kW Number of Stages: 3 MOC: Carbon Steel	From Quote	$2,000,000	1	1	2.5	$5,000,000	$5,000,000
J-101 A/B	Pitch Reactor Product Screw Conveyor	2	Length: 6 m Width: 1.5 m	$12,500	$17,000	1	1	2.4	$40,000	$81,000
J-101 A/B - Motor	Pitch Reactor Product Screw Conveyor Motor	2	Power: 870 W	$300	$400	1	1	2	$810	$1,600
J-102 A/B	Crusher Feed Belt Conveyor	2	Length: 3 m Width: 1.5 m	$10,000	$13,000	1	1	2.4	$32,000	$64,000
J-102 A/B - Motor	Pitch Reactor Product Screw Conveyor Motor	2	Power: 430 W	$250	$340	1	1	2	$670	$1,300
J-103 A/B	Mesophase Pitch Belt Conveyor	2	Length: 150 m Width: 1.5 m	$100,000	$130,000	1	1	2.4	$320,000	$640,000

(continued)

Table 97. Broad cost estimate for base design with mesophase pitch recovery cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
J-103 A/B - Motor	Pitch Reactor Product Screw Conveyor Motor	2	Power: 16 kW	$1500	$2000	1	1	2	$4,000	$8,100
L-101 A/B	PreCracking Pump	2	Power: 70 kW Suction Pressure: 110 kPa MOC: Stainless Steel	$12,500	$17,000	1.9	1	4.5	$76,000	$150,000
L-103 A/B	Pre Naphtha Decarbox	2	Power: 17 kW Suction Pressure: 120 kPa MOC: Stainless Steel	$10,000	$13,000	1.9	1	4.5	$60,000	$120,000
L-104 A/B	Atmospheric Reflux	2	Power: 1.6 kW Suction Pressure: 100 kPa MOC: Stainless Steel	$4,000	$5,400	1.9	1	3.2	$17,000	$34,000
L-105 A/B	Atmospheric Bottoms	2	Power: 810 W Suction Pressure: 110 kPa MOC: Stainless Steel	$3,900	$5,200	1.9	1	3.2	$17,000	$34,000
L-106 A/B	Vacuum Column Bottom	2	Power: 4.3 kW Suction Pressure: 33 kPa MOC: Stainless Steel	$5,000	$6,700	1.9	1	3.2	$21,000	$43,000
L-107 A/B	Vacuum Bottoms	2	Power: 760 W Suction Pressure: 100 kPa MOC: Stainless Steel	$3,800	$5,100	1.9	1	3.2	$16,000	$33,000
L-108 A/B	Vacuum Reflux	2	Power: 5.1 kW Suction Pressure: 100 kPa MOC: Stainless Steel	$5,500	$7,400	1.9	1	3.2	$24,000	$47,000
L-109 A/B	PreDiesel Decarbox	2	Power: 29 kW Suction Pressure: 120 kPa MOC: Stainless Steel	$10,750	$14,000	1.9	1	4.5	$65,000	$130,000
L-110 A/B	PreJet-Diesel Cut Heat Pump	2	Power: 1.1 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$4,000	$5,400	1.4	1	3.2	$17,000	$34,000
L-111 A/B	Naphtha Product	2	Power: 200 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,200	$4,300	1.4	1	3.2	$14,000	$28,000

(continued)

Table 97. Broad cost estimate for base design with mesophase pitch recovery cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-112 A/B	Jet Diesel Cut Reflux	2	Power: 4.4 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$5,250	$7,100	1.4	1	3.2	$23,000	$45,000
L-113 A/B	Jet Diesel Cut Bottoms	2	Power: 530 W Suction Pressure: 120 kPa MOC: Carbon Steel	$3,500	$4,700	1.4	1	3.2	$15,000	$30,000
L-114 A/B	Diesel Fuel Oil Cut Reflux	2	Power: 6.7 kW Suction Pressure: 100 kPa MOC: Stainless Steel	$8,500	$11,000	1.9	1	3.2	$37,000	$73,000
L-115 A/B	Diesel Fuel Oil Cut Bottoms	2	Power: 31 W Suction Pressure: 140 kPa MOC: Stainless Steel	$2,500	$3,400	1.9	1	3.2	$11,000	$21,000
L-116 A/B	Flash 5 Pump	2	Power: 48 W Suction Pressure: 100 kPa MOC: Stainless Steel	$2,750	$3,700	1.9	1	3.2	$12,000	$24,000
L-118 A/B	Jet Fuel Product	2	Power: 540 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,500	$4,700	1.4	1	3.2	$15,000	$30,000
L-119 A/B	Naphtha Jet Reflux	2	Power: 5.0 kW Suction Pressure: 110 kPa MOC: Carbon Steel	$5,250	$7,100	1.4	1	3.2	$23,000	$45,000
L-120 A/B	Naphtha Jet Bottoms	2	Power: 510 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,250	$4,400	1.4	1	3.2	$14,000	$28,000
L-121 A/ B	Debutanizer reflux	2	Power: 1.7 kW Suction Pressure: 820 kPa MOC: Carbon Steel	$4,200	$5,600	1.4	1	3.2	$18,000	$36,000
L-127 A/B	Syngas Reflux	2	Power: 6 kW Suction Pressure: 2700 kPa MOC: Carbon Steel	$5,500	$7,400	1.4	1	3.2	$24,000	$47,000
L-128 A/B	Flash 7 Pump	2	Power: 250 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,300	$4,400	1.4	1	3.2	$14,000	$28,000

(continued)

Table 97. Broad cost estimate for base design with mesophase pitch recovery cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-129 A/B	Diesel Product	2	Power: 330 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,400	$4,600	1.4	1	3.2	$15,000	$29,000
L-130 A/B	Fuel Oil Pump	2	Power: 790 W Suction Pressure: 7 kPa MOC: Carbon Steel	$3,850	$5,200	1.4	1	3.2	$17,000	$33,000
P-101	Refrigeration System	1	Load: 820-890 metric tons Power: 200 Volts	From Quote	$1,800,000	1	1	3.2	$5,900,000	$5,900,000
Q-101	TTCR Boiler	1	Duty: 65,000 kW	From Quote	$2,100,000	1	1	3.2	$6,700,000	$6,700,000
Q-102	High Pressure Steam Boiler	1	Duty: 78,000 kW	From Quote	$2,300,000	1	1	3.2	$7,400,000	$7,400,000
R-101	TTCR	1	Diameter: 6.1 m Length: 12.2 m Tubes: 10300 MOC: cs/inconel	From Quote	$30,000,000	0.7	1	3.2	$21,000,000	$21,000,000
R-102 A/B	Naphtha Decarboxylation Reactor	2	Diameter: 2.9 m Length: 17 m MOC: Stainless Steel Clad	From Quote	$840,000	1	1	3.2	$2,700,000	$5,400,000
R-103 A/B	Diesel Decarboxylation Reactor	2	Diameter: 3.2 m Length: 19 m MOC: Stainless Steel Clad	From Quote	$1,000,000	1	1	3.2	$3,300,000	$6,700,000
R-104 A/B	Pitching Reactor	2	Diameter: 1.2 m Height: 3.6 m MOC: Stainless Steel Clad	$360,000	$480,000	1	1	3.2	$1,500,000	$3,100,000

Total Bare Module Cost	CTBM	$76,000,000
Contingency and Fees	CTBM*0.18	$14,000,000
Total Module Cost	CTM	$90,000,000
Auxiliary Facilities	CTM*0.2	$18,000,000
Fixed Capital Investment	FCI	$110,000,000
Working Capital	FCI*0.15	$16,000,000
Chemicals & Catalysts		$19,000,000
Total Capital Investment	TCI	$140,000,000

Notes: Actual numbers may be off due to rounding

Table 98. Operating expense summary for base design with mesophase pitch recovery.

Year	Chemicals and Catalysts	Operating Labor	Maintenance	Utilities	Yearly Total
1	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000
2	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000
3	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000
4	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000
5	$19,000,000	$2,600,000	$6,500,000	$4,300,000	$32,000,000
6	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000
7	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000
8	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000
9	$19,000,000	$2,600,000	$6,500,000	$4,300,000	$32,000,000
10	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000
11	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000
12	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000
13	$19,000,000	$2,600,000	$6,500,000	$4,300,000	$32,000,000
14	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000
15	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000
16	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000
17	$19,000,000	$2,600,000	$6,500,000	$4,300,000	$32,000,000
18	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000
19	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000
20	$750,000	$2,600,000	$6,500,000	$4,300,000	$14,000,000

Notes: Actual numbers may be off due to rounding

Table 99. Cash flow sheet for base design with mesophase pitch recovery.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR	Present Value @ DCFROR
-1	$-	$-	$-	$-	$-	$-	$-	($54,000)	($54,000)	($60,000)	($110,000)
0	$-	$-	$-	$-	$-	$-	$-	($89,000)	($89,000)	($89,000)	($89,000)
1	$660,000	$300,000	$14,000	$340,000	($17,000)	$330,000	($140,000)		$210,000	$190,000	$100,000
2	$660,000	$300,000	$14,000	$340,000	($15,000)	$330,000	($140,000)		$210,000	$170,000	$50,000
3	$660,000	$300,000	$14,000	$340,000	($13,000)	$330,000	($140,000)		$210,000	$150,000	$24,000
4	$660,000	$300,000	$14,000	$340,000	($12,000)	$330,000	($140,000)		$210,000	$130,000	$12,000
5	$660,000	$300,000	$32,000	$330,000	($10,000)	$320,000	($130,000)		$200,000	$110,000	$5,500
6	$660,000	$300,000	$14,000	$340,000	($9,000)	$330,000	($140,000)		$210,000	$100,000	$2,800
7	$660,000	$300,000	$14,000	$340,000	($7,900)	$340,000	($140,000)		$200,000	$93,000	$1,400
8	$660,000	$300,000	$14,000	$340,000	($7,000)	$340,000	($140,000)		$200,000	$83,000	$670
9	$660,000	$300,000	$32,000	$330,000	($6,200)	$320,000	($130,000)		$190,000	$70,000	$310
10	$660,000	$300,000	$14,000	$340,000	($5,800)	$340,000	($140,000)		$200,000	$66,000	$160
11	$660,000	$300,000	$14,000	$340,000	($5,800)	$340,000	($140,000)		$200,000	$59,000	$79
12	$660,000	$300,000	$14,000	$340,000	($5,800)	$340,000	($140,000)		$200,000	$52,000	$39
13	$660,000	$300,000	$32,000	$330,000	($5,800)	$320,000	($130,000)		$190,000	$44,000	$18
14	$660,000	$300,000	$14,000	$340,000	($5,800)	$340,000	($140,000)		$200,000	$42,000	$9
15	$660,000	$300,000	$14,000	$340,000	($5,800)	$340,000	($140,000)		$200,000	$37,000	$5
16	$660,000	$300,000	$14,000	$340,000	($5,800)	$340,000	($140,000)		$200,000	$33,000	$2
17	$660,000	$300,000	$32,000	$330,000	($5,800)	$320,000	($130,000)		$190,000	$28,000	$1
18	$660,000	$300,000	$14,000	$340,000		$340,000	($140,000)		$200,000	$26,000	$1
19	$660,000	$300,000	$14,000	$340,000		$340,000	($140,000)		$200,000	$23,000	$0
20	$660,000	$300,000	$14,000	$340,000		$340,000	($140,000)	$16,000	$220,000	$23,000	$0
									NPV@HR	$1,400,000	$0
									DCFROR	104%	
									HR	12%	

Notes: Dollar values are in thousands

Actual numbers may be off due to rounding

Numbers in parenthesis represent negative numbers

Table 100. Cash flow sheet for base design with mesophase pitch recovery and a soybean oil price of $1.23/kg.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR
-1	$-	$-	$-	$-	$-	$-	$-	($54,000)	($54,000)	($60,000)
0	$-	$-	$-	$-	$-	$-	$-	($89,000)	($89,000)	($89,000)
1	$660,000	$610,000	$14,000	$30,000	($17,000)	$13,000	($5,400)		$24,000	$22,000
2	$660,000	$610,000	$14,000	$30,000	($15,000)	$15,000	($6,300)		$24,000	$19,000
3	$660,000	$610,000	$14,000	$30,000	($13,000)	$17,000	($7,000)		$23,000	$16,000
4	$660,000	$610,000	$14,000	$30,000	($12,000)	$18,000	($7,600)		$22,000	$14,000
5	$660,000	$610,000	$32,000	$12,000	($10,000)	$1,800	($760)		$11,000	$6,400
6	$660,000	$610,000	$14,000	$30,000	($9,000)	$21,000	($8,700)		$21,000	$11,000
7	$660,000	$610,000	$14,000	$30,000	($7,900)	$22,000	($9,100)		$21,000	$9,400
8	$660,000	$610,000	$14,000	$30,000	($7,000)	$23,000	($9,500)		$20,000	$8,300
9	$660,000	$610,000	$32,000	$12,000	($6,200)	$5,800	($2,400)		$9,600	$3,500
10	$660,000	$610,000	$14,000	$30,000	($5,800)	$24,000	($10,000)		$20,000	$6,400
11	$660,000	$610,000	$14,000	$30,000	($5,800)	$24,000	($10,000)		$20,000	$5,700
12	$660,000	$610,000	$14,000	$30,000	($5,800)	$24,000	($10,000)		$20,000	$5,100
13	$660,000	$610,000	$32,000	$12,000	($5,800)	$6,200	($2,600)		$9,400	$2,200
14	$660,000	$610,000	$14,000	$30,000	($5,800)	$24,000	($10,000)		$20,000	$4,100
15	$660,000	$610,000	$14,000	$30,000	($5,800)	$24,000	($10,000)		$20,000	$3,600
16	$660,000	$610,000	$14,000	$30,000	($5,800)	$24,000	($10,000)		$20,000	$3,300
17	$660,000	$610,000	$32,000	$12,000	($5,800)	$6,200	($2,600)		$9,400	$1,400
18	$660,000	$610,000	$14,000	$30,000		$30,000	($12,000)		$18,000	$2,300
19	$660,000	$610,000	$14,000	$30,000		$30,000	($12,000)		$18,000	$2,000
20	$660,000	$610,000	$14,000	$30,000		$30,000	($12,000)	$16,000	$34,000	$3,500
									NPV@HR	$0
									DCFROR	12%
									HR	12%

Notes: Dollar values are in thousands

Actual numbers may be off due to rounding

Numbers in parenthesis represent negative numbers

Table 101. Cash Flow sheet for base design with mesophase pitch recovery and a mesophase pitch price of $4.08/kg.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR
-1	$-	$-	$-	$-	$-	$-	$-	($54,000)	($54,000)	($60,000)
0	$-	$-	$-	$-	$-	$-	$-	($89,000)	($89,000)	($89,000)
1	$340,000	$300,000	$14,000	$30,000	($17,000)	$13,000	($5,400)		$24,000	$22,000
2	$340,000	$300,000	$14,000	$30,000	($15,000)	$15,000	($6,300)		$24,000	$19,000
3	$340,000	$300,000	$14,000	$30,000	($13,000)	$17,000	($7,000)		$23,000	$16,000
4	$340,000	$300,000	$14,000	$30,000	($12,000)	$18,000	($7,600)		$22,000	$14,000
5	$340,000	$300,000	$32,000	$12,000	($10,000)	$1,800	($760)		$11,000	$6,400
6	$340,000	$300,000	$14,000	$30,000	($9,000)	$21,000	($8,700)		$21,000	$11,000
7	$340,000	$300,000	$14,000	$30,000	($7,900)	$22,000	($9,100)		$21,000	$9,400
8	$340,000	$300,000	$14,000	$30,000	($7,000)	$23,000	($9,500)		$20,000	$8,300
9	$340,000	$300,000	$32,000	$12,000	($6,200)	$5,800	($2,400)		$9,600	$3,500
10	$340,000	$300,000	$14,000	$30,000	($5,800)	$24,000	($10,000)		$20,000	$6,400
11	$340,000	$300,000	$14,000	$30,000	($5,800)	$24,000	($10,000)		$20,000	$5,700
12	$340,000	$300,000	$14,000	$30,000	($5,800)	$24,000	($10,000)		$20,000	$5,100
13	$340,000	$300,000	$32,000	$12,000	($5,800)	$6,200	($2,600)		$9,400	$2,200
14	$340,000	$300,000	$14,000	$30,000	($5,800)	$24,000	($10,000)		$20,000	$4,100
15	$340,000	$300,000	$14,000	$30,000	($5,800)	$24,000	($10,000)		$20,000	$3,600
16	$340,000	$300,000	$14,000	$30,000	($5,800)	$24,000	($10,000)		$20,000	$3,300
17	$340,000	$300,000	$32,000	$12,000	($5,800)	$6,200	($2,600)		$9,400	$1,400
18	$340,000	$300,000	$14,000	$30,000		$30,000	($12,000)		$18,000	$2,300
19	$340,000	$300,000	$14,000	$30,000		$30,000	($12,000)		$18,000	$2,000
20	$340,000	$300,000	$14,000	$30,000		$30,000	($12,000)	$16,000	$34,000	$3,500
									NPV@HR	$0
									DCFROR	12%
									HR	12%

Notes: Dollar values are in thousands

Actual values may be off due to rounding

Numbers in parenthesis represent negative numbers

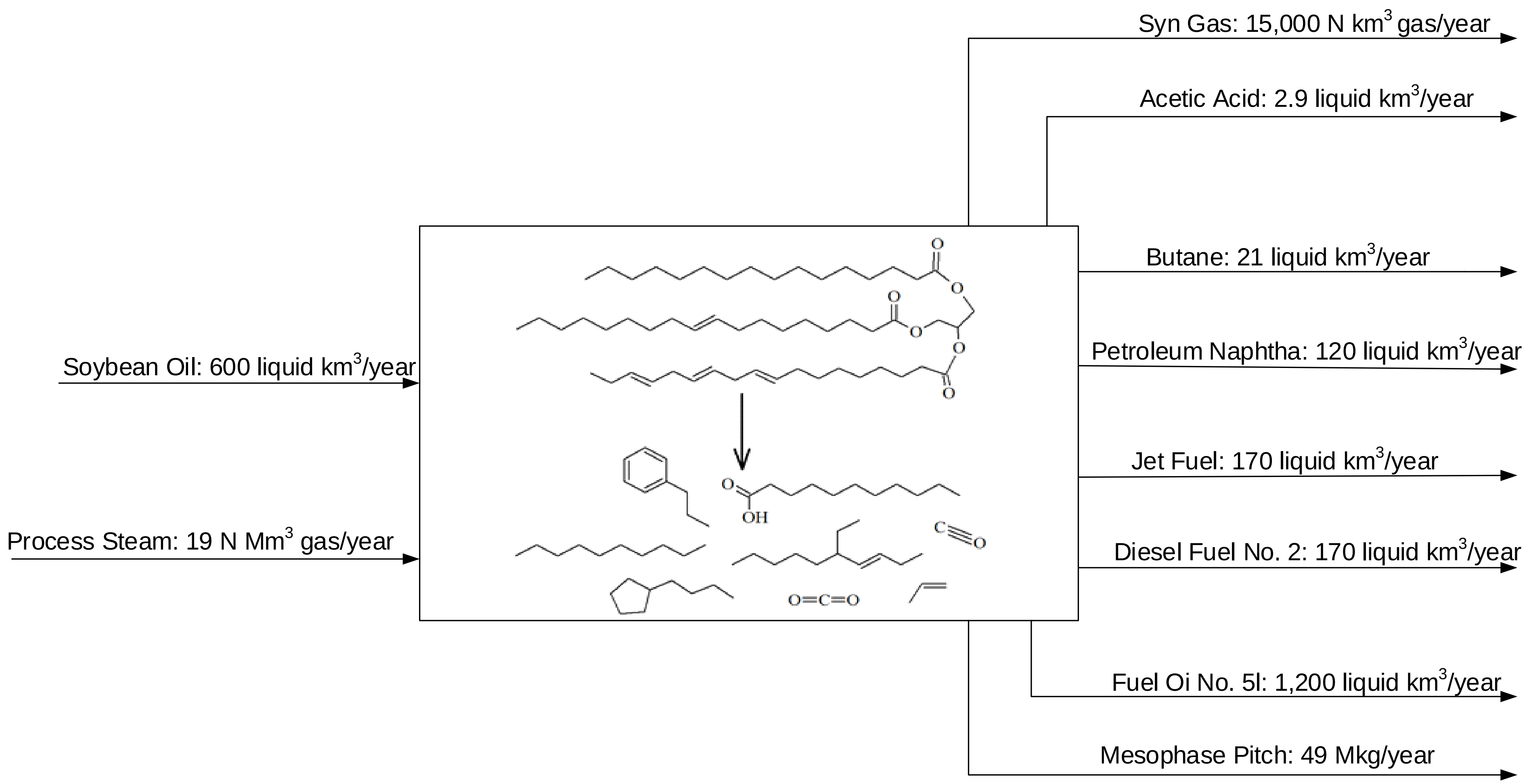
Table 102. Cash flow sheet for base design with mesophase pitch recovery and a mesophase pitch price of $21.00/kg.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR
-1	$-	$-	$-	$-	$-	$-	$-	($54,000)	($54,000)	($60,000)
0	$-	$-	$-	$-	$-	$-	$-	($89,000)	($89,000)	($89,000)
1	$1,200,000	$300,000	$14,000	$860,000	($17,000)	$840,000	($350,000)		$510,000	$460,000
2	$1,200,000	$300,000	$14,000	$860,000	($15,000)	$840,000	($350,000)		$510,000	$410,000
3	$1,200,000	$300,000	$14,000	$860,000	($13,000)	$840,000	($350,000)		$510,000	$360,000
4	$1,200,000	$300,000	$14,000	$860,000	($12,000)	$850,000	($350,000)		$510,000	$320,000
5	$1,200,000	$300,000	$32,000	$840,000	($10,000)	$830,000	($340,000)		$500,000	$280,000
6	$1,200,000	$300,000	$14,000	$860,000	($9,000)	$850,000	($350,000)		$510,000	$260,000
7	$1,200,000	$300,000	$14,000	$860,000	($7,900)	$850,000	($350,000)		$510,000	$230,000
8	$1,200,000	$300,000	$14,000	$860,000	($7,000)	$850,000	($350,000)		$510,000	$200,000
9	$1,200,000	$300,000	$32,000	$840,000	($6,200)	$830,000	($340,000)		$490,000	$180,000
10	$1,200,000	$300,000	$14,000	$860,000	($5,800)	$850,000	($350,000)		$510,000	$160,000
11	$1,200,000	$300,000	$14,000	$860,000	($5,800)	$850,000	($350,000)		$510,000	$150,000
12	$1,200,000	$300,000	$14,000	$860,000	($5,800)	$850,000	($350,000)		$510,000	$130,000
13	$1,200,000	$300,000	$32,000	$840,000	($5,800)	$830,000	($340,000)		$490,000	$110,000
14	$1,200,000	$300,000	$14,000	$860,000	($5,800)	$850,000	($350,000)		$510,000	$100,000
15	$1,200,000	$300,000	$14,000	$860,000	($5,800)	$850,000	($350,000)		$510,000	$92,000
16	$1,200,000	$300,000	$14,000	$860,000	($5,800)	$850,000	($350,000)		$510,000	$82,000
17	$1,200,000	$300,000	$32,000	$840,000	($5,800)	$830,000	($340,000)		$490,000	$72,000
18	$1,200,000	$300,000	$14,000	$860,000		$860,000	($350,000)		$500,000	$65,000
19	$1,200,000	$300,000	$14,000	$860,000		$860,000	($350,000)		$500,000	$58,000
20	$1,200,000	$300,000	$14,000	$860,000		$860,000	($350,000)	$16,000	$520,000	$54,000
									NPV@HR	$3,600,000
									DCFROR	12%
									HR	12%

Notes: Dollar values are in thousands

Actual numbers may be off due to rounding

Numbers in parenthesis represent negative numbers



Notes

1. Material balance may be off due to rounding errors.

Special Symbols / Nomenclature

Reference Drawings:

Block Flow Diagram
00-A-017

Process Flow Diagram
00-A-018

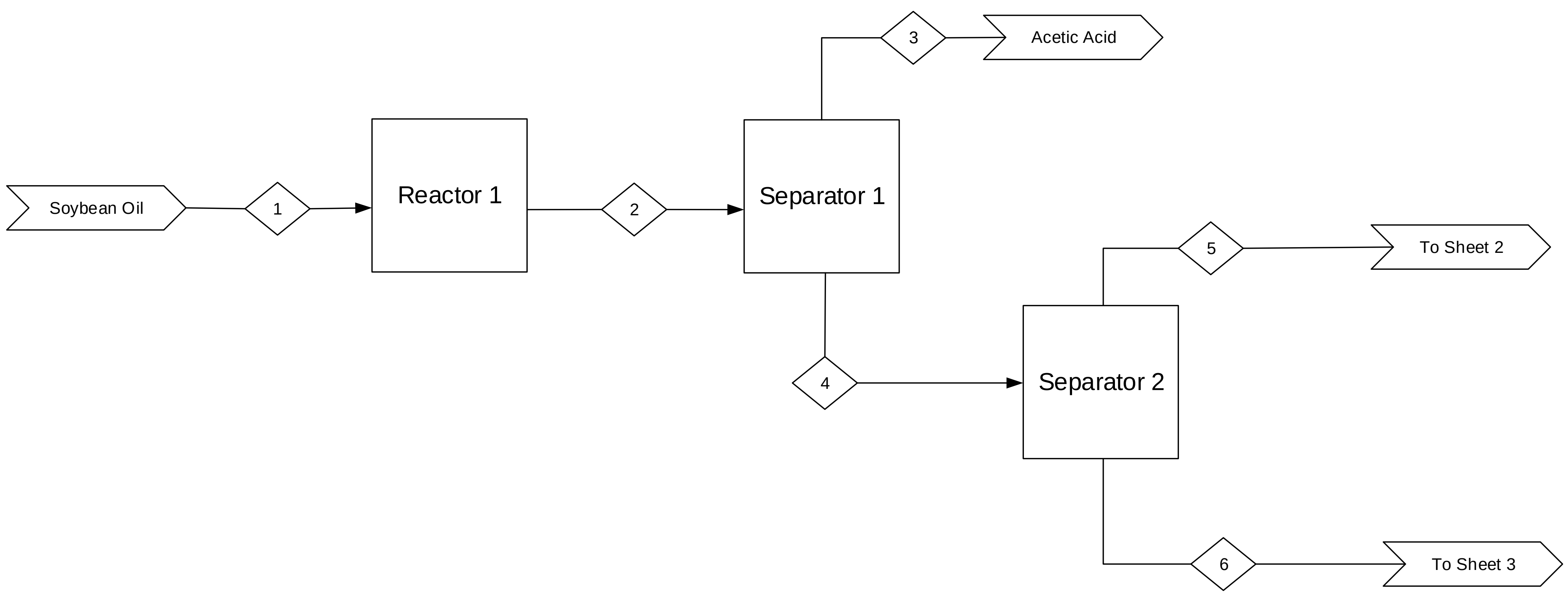
Drawing Type

Input/Output Diagram

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design with Mesophase Pitch Recovery

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-5-17	00-A-016	0



Component/Stream (kg/min)	1	2	3	4	5	6
Soybean Oil	1000	0	0	0	0	0
Acetic Acid	0	0	5	0	0	0
C1-C50	0	1000	0	1000	0	0
C1-C12	0	0	0	0	440	0
C12-C50	0	0	0	0	0	550
Total	1000	1000	5	1000	440	550

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 1: Crack incoming TG oil into fuel intermediates

Separator 1:Separate aqueous acetic acid from organic crackate

Separator 2: Separate the naphtha range fuel intermediates from the diesel range fuel intermediates

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-016

Process Flow Diagram
00-A-018

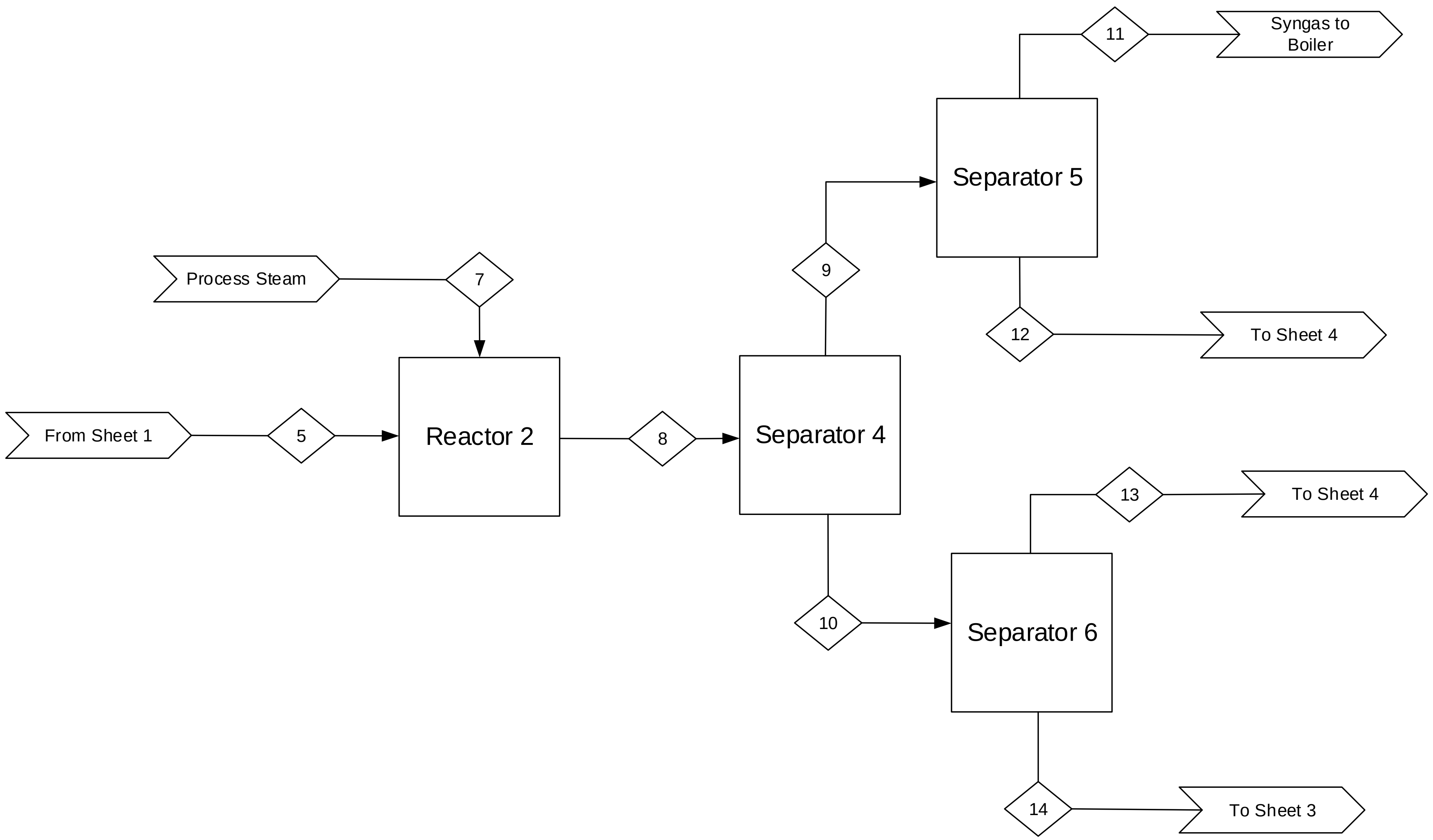
Drawing Type

Block Flow Diagrams

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design with Mesophase Pitch Recovery

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-5-17	00-A-017/1	0



Component/Stream (kg/min)	5	7	8	9	10	11	12	13	14
C1-C12	440	0	440	0	0	0	0	0	0
Steam	0	7	0	0	0	0	0	0	0
C1-C6	0	0	0	240	0	0	0	0	0
C1-C3	0	0	0	0	0	160	0	0	0
C4-C6	0	0	0	0	0	0	82	0	0
C7-C10	0	0	0	0	0	0	0	64	0
C11-C13	0	0	0	0	0	0	0	0	140
C7-C13	0	0	0	0	200	0	0	0	0
Total	440	7	440	240	200	160	82	64	140

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 2: Reacts the carboxylic acids and alkenes to produce hydrocarbons.

Separator 4: Removes light ends from naphtha range fuel intermediates.

Separator 5: Removes syngas from butane and naphtha intermediates.

Separator 6: Separates petroleum naphtha intermediates from jet fuel range fuel intermediates.

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

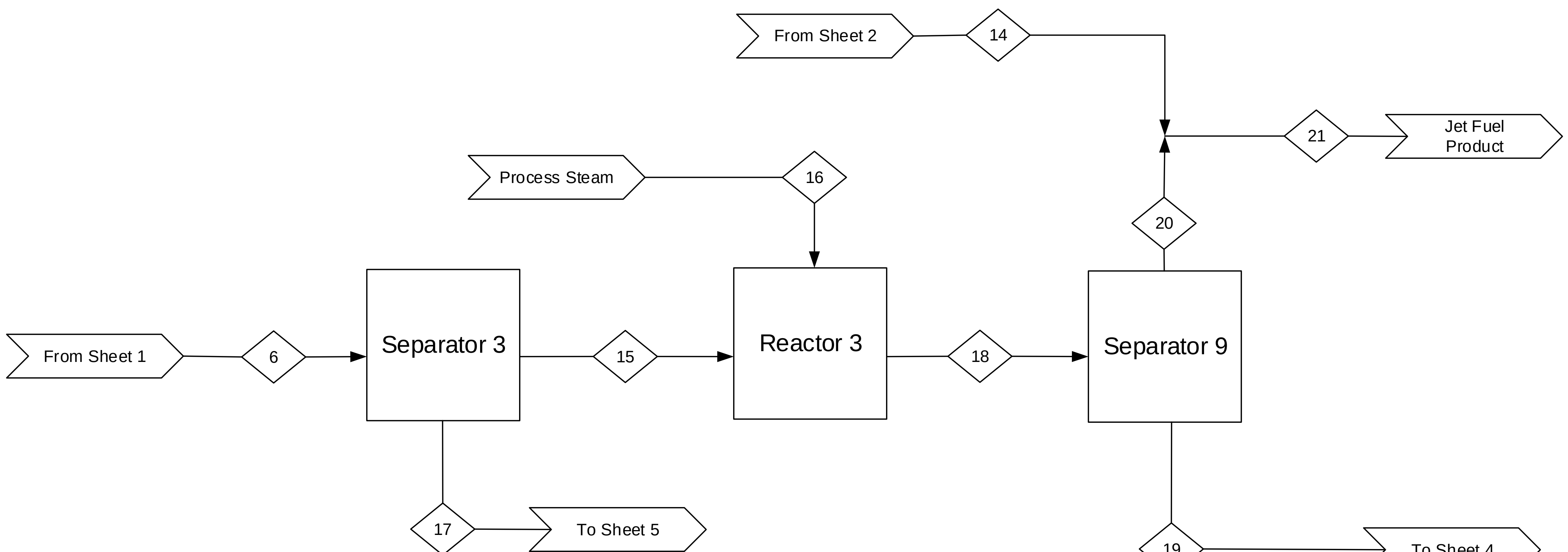
Input/Output Diagram
00-A-016

Process Flow Diagram
00-A-018

Drawing Type
Block Flow Diagram

Title
Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design with Mesophase Pitch Recovery

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-5-17	00-A-017/2	0



Component/Stream (kg/min)	6	14	15	16	17	18	19	20	21
Steam	0	0	0	9	0	0	0	0	0
C12-C50	550	0	0	0	0	0	0	0	0
C30-C50	0	0	0	0	280	0	0	0	0
C12-C30	0	0	280	0	0	290	0	0	0
C13-C15	0	0	0	0	0	0	0	73	0
C11-C13	0	140	0	0	0	0	0	0	0
C11-C15	0	0	0	0	0	0	0	0	210
C15-C30	0	0	0	0	0	0	220	0	0
Total	550	140	280	9	280	290	220	73	210

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 3: Reacts carboxylic acids and alkenes to produce hydrocarbons.

Separator 3: Separates diesel fuel range intermediates from the vacuum bottoms.

Separator 9: Separates jet fuel range fuel intermediates from diesel fuel range intermediates.

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram 00-A-016

Process Flow Diagram 00-A-018

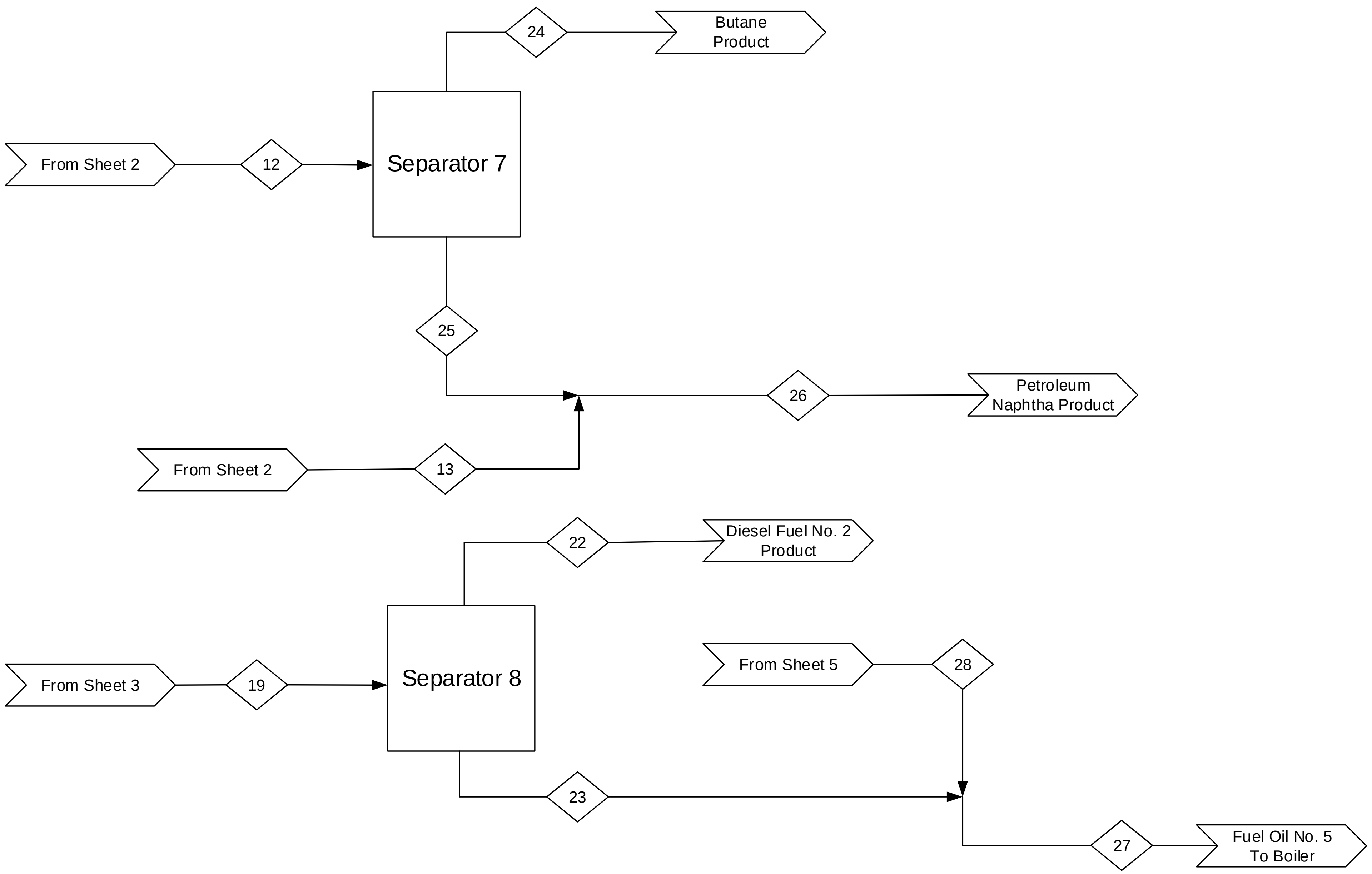
Drawing Type

Block Flow Diagram

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design with Mesophase Pitch Recovery

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-5-17	00-A-017/3	0



Component/Stream (kg/min)	12	13	19	22	23	24	25	26	27	28
C4-C6	82	0	0	0	0	0	0	0	0	0
C4	0	0	0	0	0	20	0	0	0	0
C5-C6	0	0	0	0	0	0	64	0	0	0
C7-C10	0	64	0	0	0	0	0	0	0	0
C5-C10	0	0	0	0	0	0	0	130	0	0
C15-C22	0	0	0	210	0	0	0	0	0	0
C23-C30	0	0	0	0	4	0	0	0	190	180
C15-C30	0	0	220	0	0	0	0	0	0	0
Total	82	64	220	210	4	20	64	130	190	180

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Separator 7: Separates butane byproduct from naphtha range intermediates.

Separator 8: Separates the diesel fuel no. 2 product from the fuel oi no 5. product.

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-016

Process Flow Diagram
00-A-018

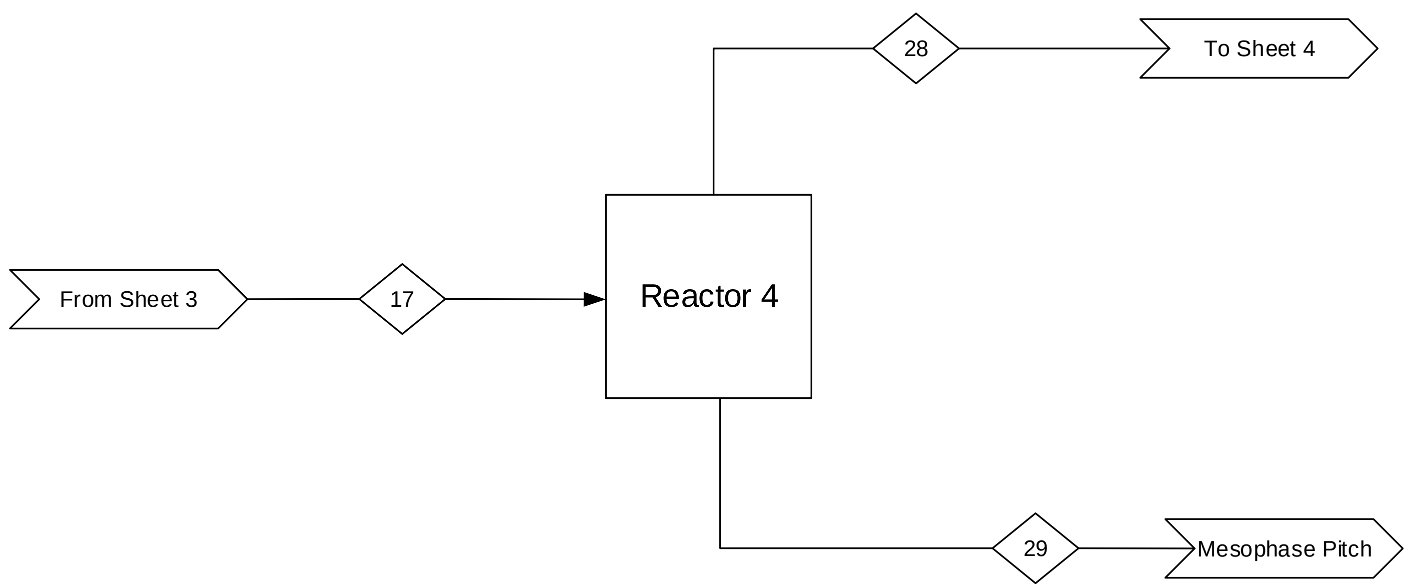
Drawing Type

Block Flow Diagram

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design with Mesophase Pitch Recovery

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-5-17	00-A-017/4	0

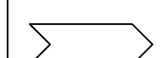


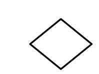
Component/Stream (kg/min)	17	28	29
C30-C50	280	0	0
C23-C30	0	180	0
Mesophase Pitch	0	0	100
Total	280	180	100

Notes

1. Drawing not to scale.
2. Mass balance may be off due to rounding.
3. Stream numbers do not correspond with PFD stream numbers.
4. Mass balances shown in kg/min.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Assume 100% separation in separators.
7. Reactor 4: Uses heat to produce mesophase pitch from vacuum bottoms, with production of fuel oil no. 5.

Special Symbols / Nomenclature


Input/Output


Stream Indicator

Reference Drawings:

Input/Output Diagram 00-A-016

Process Flow Diagram 00-A-018

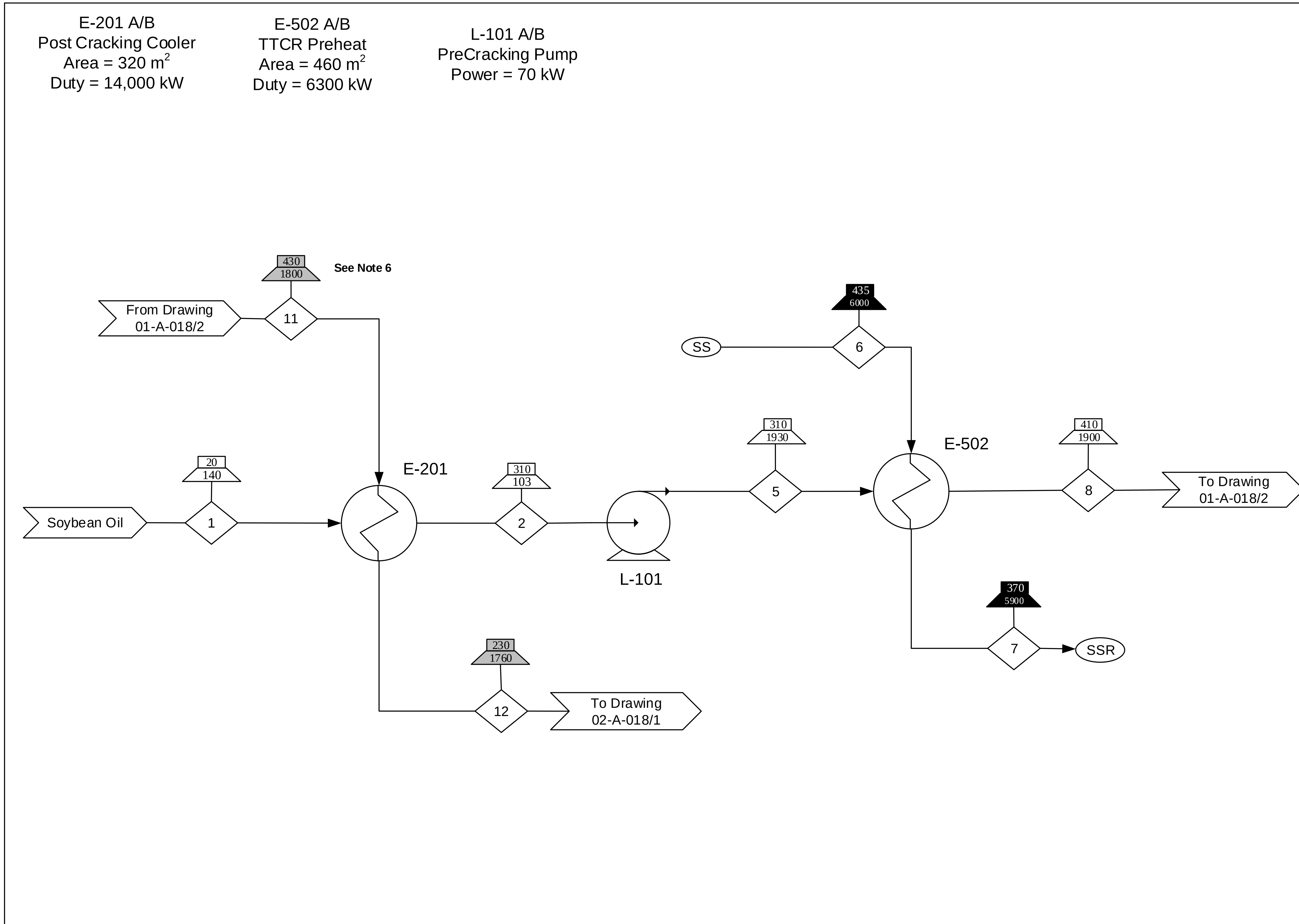
Drawing Type

Block Flow Diagram

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design with Mesophase Pitch Recovery

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-5-17	00-A-017/4	0



Component/Stream (kg/min)	1	2	5	6	7	8	11	12
Soybean Oil	1000	1000	1000	0	0	1000	0	0
C1-C50	0	0	0	0	0	0	1000	1000
Water	0	0	0	2400	2400	0	0	0
Total	1000	1000	1000	2400	2400	1000	1000	1000

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 11 and 12 is an organic, aqueous, gaseous three phase stream.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- Temperature (°C) Indicator, Two Phase
- Pressure (kPa) Indicator, Two Phase
- SS Superheated Steam
- SSR Superheated Steam Recycle

Reference Drawings:

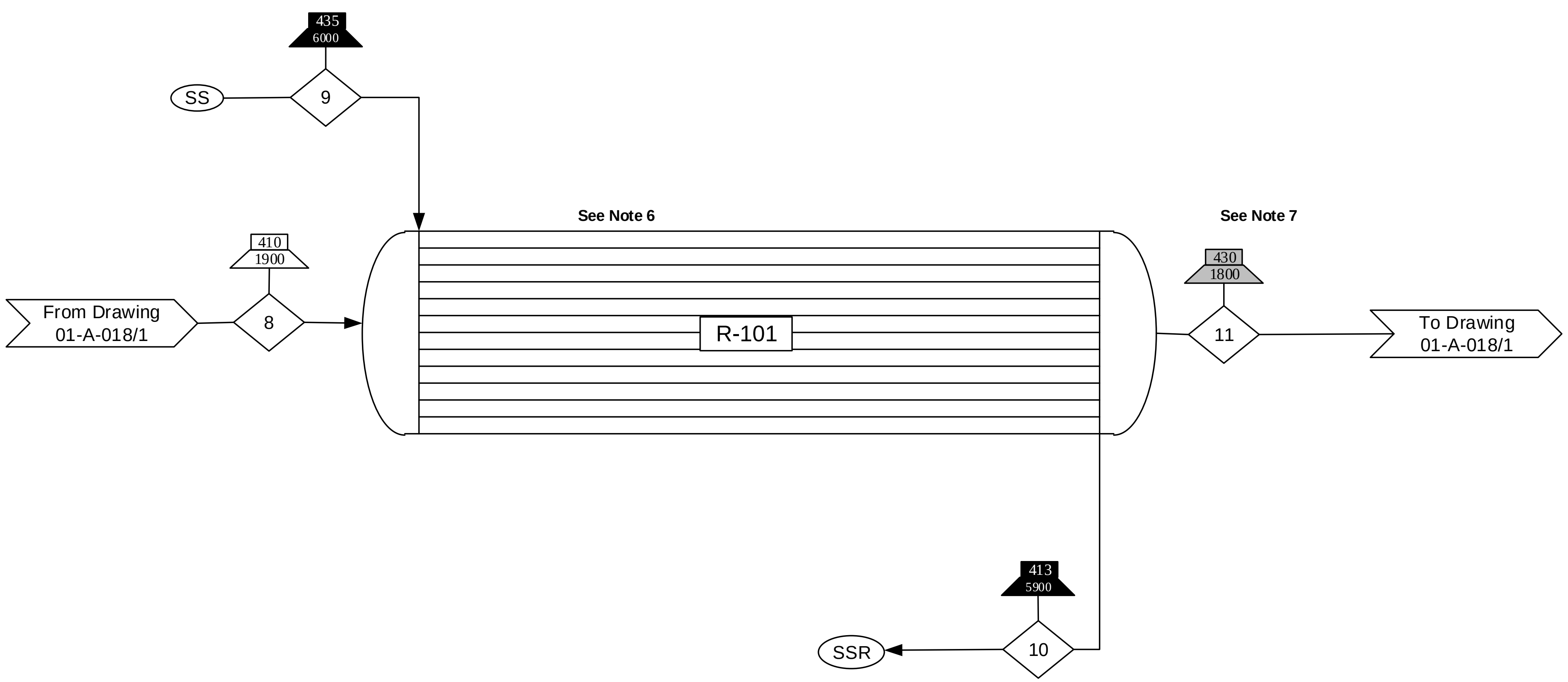
Input/Output Diagram 00-A-016
Block Flow Diagrams 00-A-017
Process Flow Diagrams 01-A-018

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch - Thermal Cracking Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	01-A-018/1	0

R-101
TTCR
Diameter= 6.1 m
Length= 12.2 m
Tubes= 10300



Component/Stream (kg/min)	8	9	10	11
Soybean Oil	1000	0	0	0
C1-C50	0	0	0	1000
Water	0	8200	8200	0
Total	1000	8200	8200	1000

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. R-101 has a residence time of 1.17 hr.

7. Stream 11 is composed of a gas phase stream with entrained liquid tars.

Special Symbols / Nomenclature

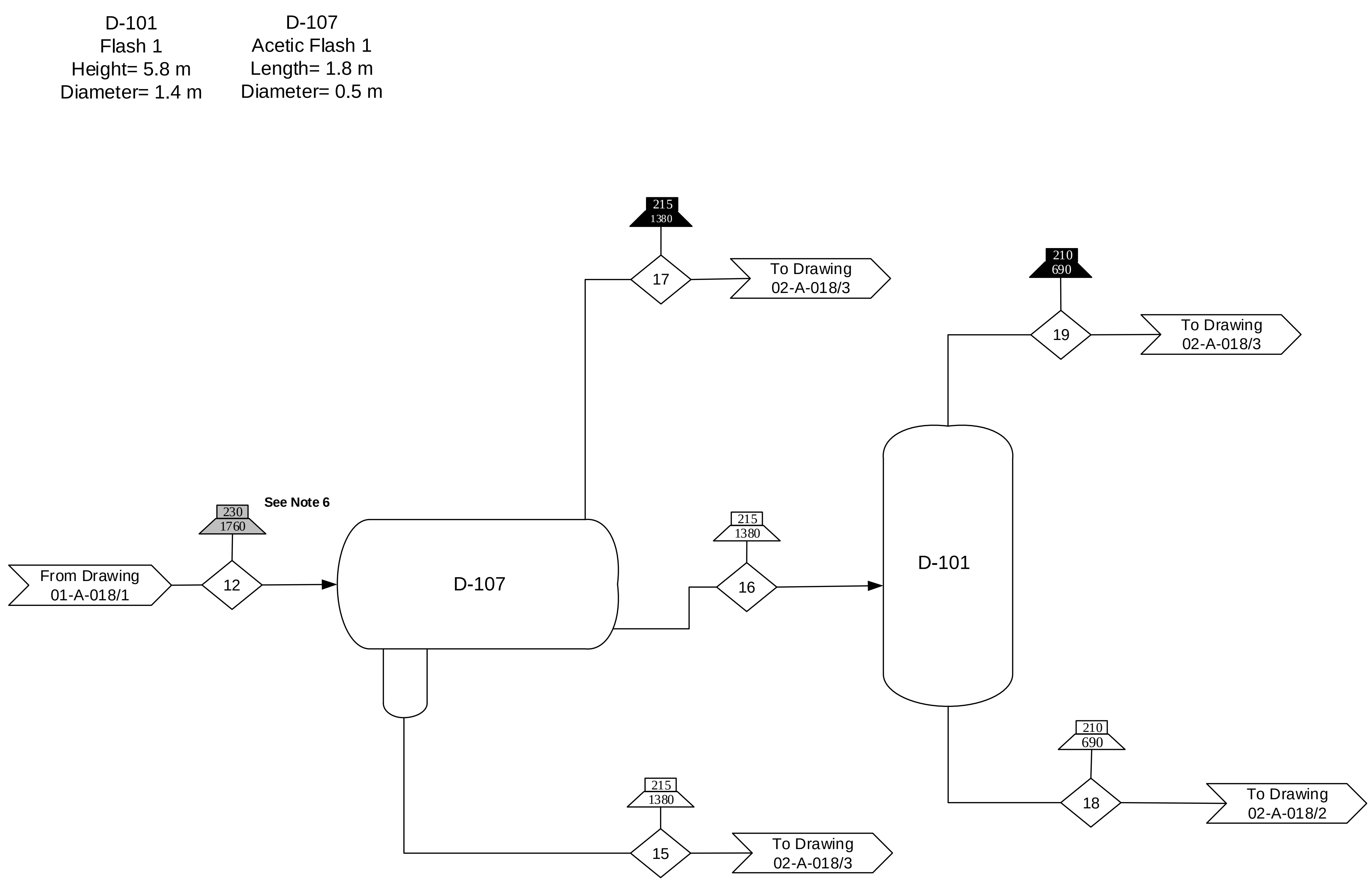
Symbol	Meaning
Diamond	Stream Indicator
Chevron	Input/Output
White rectangle	Temperature (°C) Indicator, Liquid/Solid
White trapezoid	Pressure (kPa) Indicator, Liquid/Solid
Black rectangle	Temperature (°C) Indicator, Gas
Black trapezoid	Pressure (kPa) Indicator, Gas
Grey rectangle	Temperature (°C) Indicator, Two Phase
Grey trapezoid	Pressure (kPa) Indicator, Two Phase
SS	Superheated Steam
SR	Superheated Steam Recycle

Reference Drawings:
Input/Output Diagrams
00-A-016
Block Flow Diagrams
00-A-017
Process Flow Diagrams
01-A-018
02-A-018

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch - Thermal Cracking Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	01-A-018/2	0

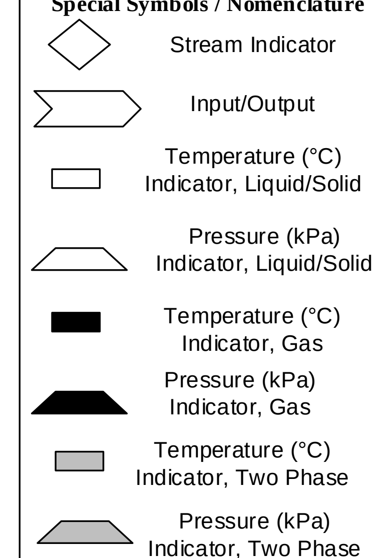


Component/Stream (kg/min)	12	15	16	17	18	19
C1-C50	1000	0	0	0	0	0
C1-C8	0	0	0	210	0	9
C7-C50	0	0	780	0	770	0
Acetic Acid	0	3	0	Trace	0	0
Propionic Acid	0	1	0	0	0	0
Total	1000	4	780	210	770	9

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 12 is composed of an aqueous and organic three phase stream.

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
01-A-018
02-A-018

Drawing Type
Process Flow Diagram

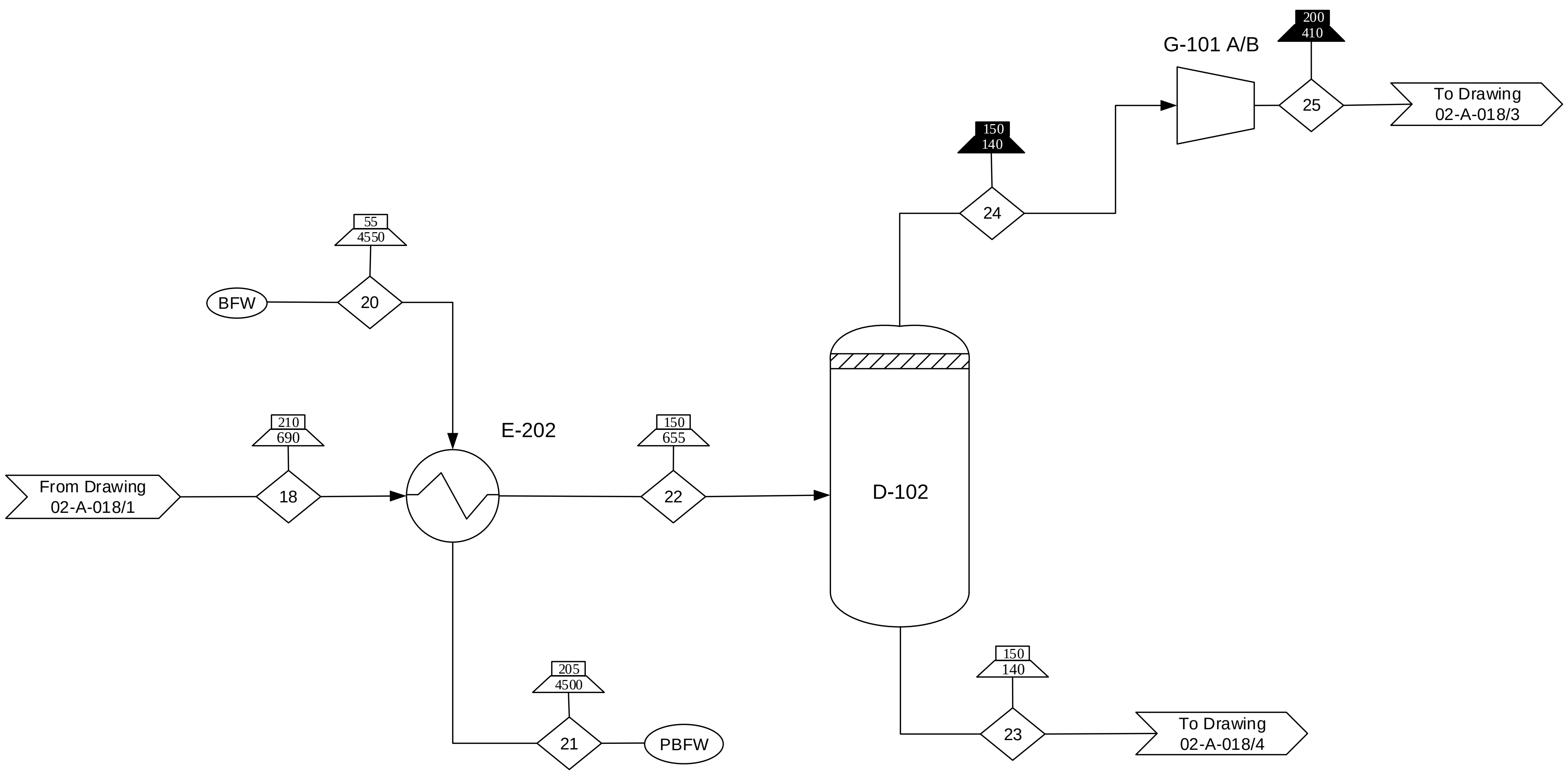
Title
Biorefinery Base Design with Mesophase Pitch- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	02-A-018/1	0

D-102
Flash 2
Height= 5.3 m
Diameter= 1.4 m

E-202 A/B
Flash 2 Cooler
Area= 170 m^2
Duty= 2700 kW

G-101 A/B
Flash 2 Compressor
Power= 17 kW



Component/Stream (kg/min)	18	20	21	22	23	24	25
C1-C8	0	0	0	0	0	20	9
C7-C50	770	0	0	770	770	0	0
Water	0	85	85	0	0	0	0
Total	770	85	85	770	770	20	9

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

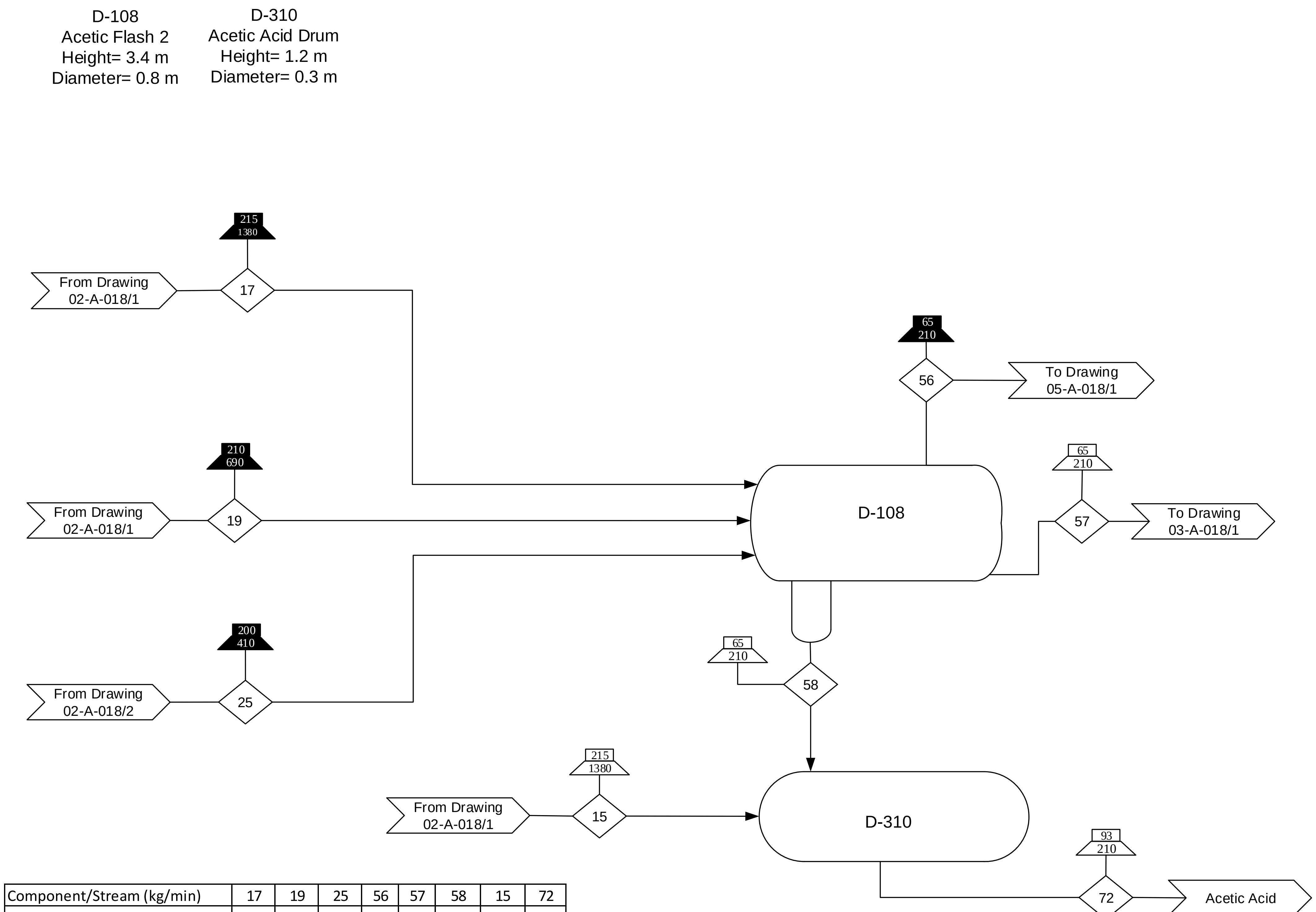
Reference Drawings:

Input/Output Diagrams
00-A-016
Block Flow Diagrams
00-A-017
Process Flow Diagrams
02-A-018

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	02-A-018/2	0



Component/Stream (kg/min)	17	19	25	56	57	58	15	72
C1-C8	210	9	9	0	0	0	0	0
C1-C6	0	0	0	170	0	0	0	0
C6-C8	0	0	0	0	54	0	0	0
Water	0	0	0	0	0	0	0	0
Acetic Acid	0	Trace	Trace	Trace	0	1	3	4
Propionic Acid	0	Trace	Trace	0	0	Trace	1	1
Total	210	9	9	170	54	1	4	5

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°C) Indicator, Liquid/Solid

Pressure (kPa) Indicator, Liquid/Solid

Temperature (°C) Indicator, Gas

Pressure (kPa) Indicator, Gas

Reference Drawings:

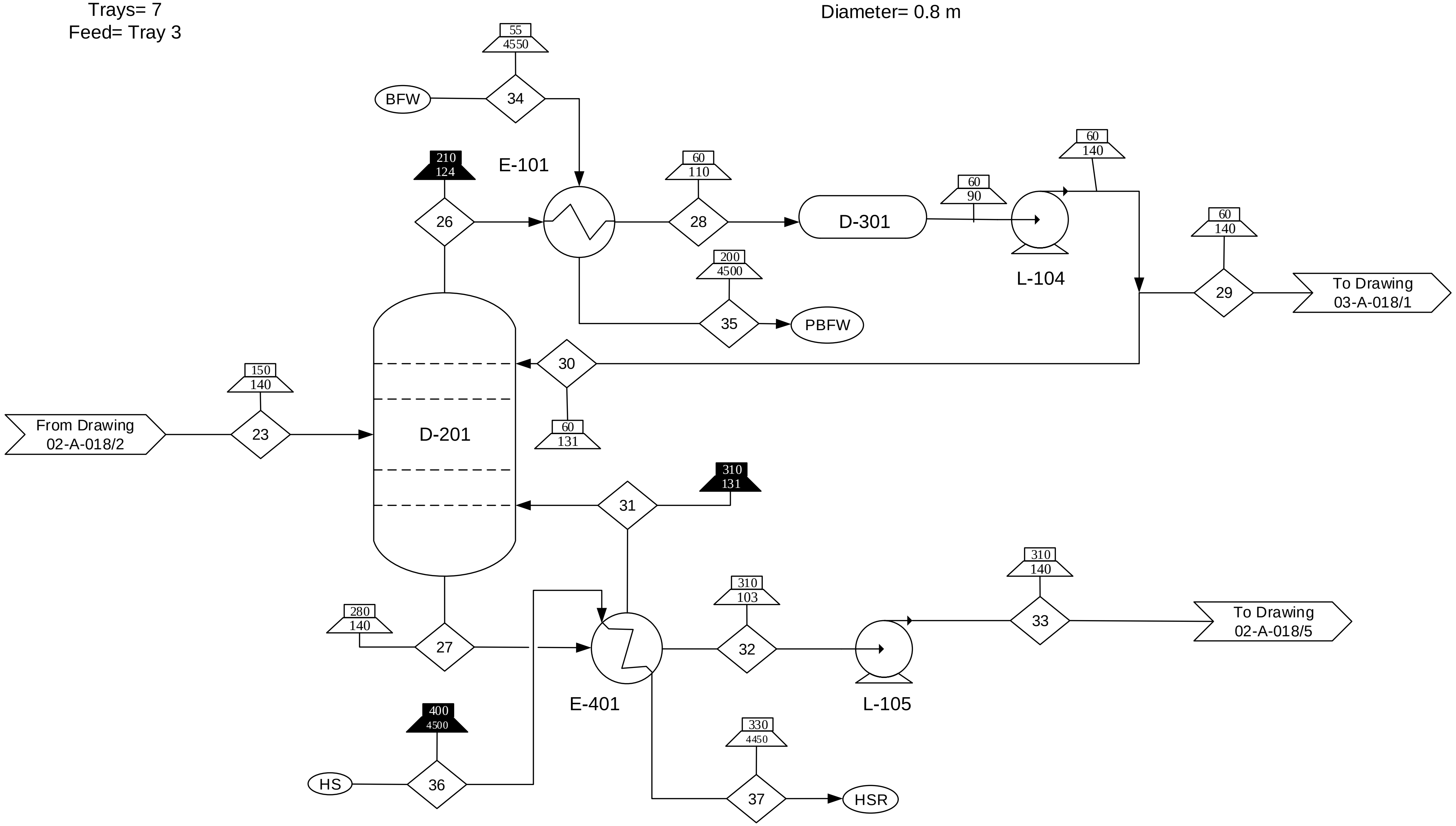
Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
02-A-018
03-A-018
05-A-018

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	02-A-018/3	0

D-201	E-101 A/B	E-401 A/B	D-301	L-104 A/B	L-105 A/B
Atmospheric Column	Atmospheric Column Condenser	Atmospheric Column Reboiler	Atmospheric Column Reflux Drum	Atmospheric Reflux	Atmospheric Bottoms
Height= 8.4 m	Area= 660 m^2	Area= 200 m^2	Length= 3 m	Power= 1.6 kW	Power= 810 W
Diameter= 2.4 m	Duty= 2500 kW	Duty= 7300 kW	Diameter= 0.8 m		
Trays= 7					
Feed= Tray 3					



Component/Stream (kg/min)	23	26	27	28	29	30	31	32	33	34	35	36	37
C7-C12	0	180	0	180	170	13	0	0	0	0	0	0	0
C7-C50	770	0	1450	0	0	0	860	0	0	0	0	0	0
C13-C50	0	0	0	0	0	0	0	590	590	0	0	0	0
Water	0	0	0	0	0	0	0	0	0	78	78	2540	2540
Total	770	180	1450	180	170	13	860	590	590	78	78	2540	2540

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- HS: High Pressure Steam
- HSR: High Pressure Steam Condensate
- BFW: Boiler Feed Water
- PBFW: Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
02-A-018
03-A-018

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	02-A-018/4	0

D-202
Vacuum Column
Height= 20 m
Diameter= 2.9 m
Trays= 20
Feed= Tray 5

E-102 A/B
Vacuum Column Condenser
Area= 55 m^2
Duty= 5500 kW

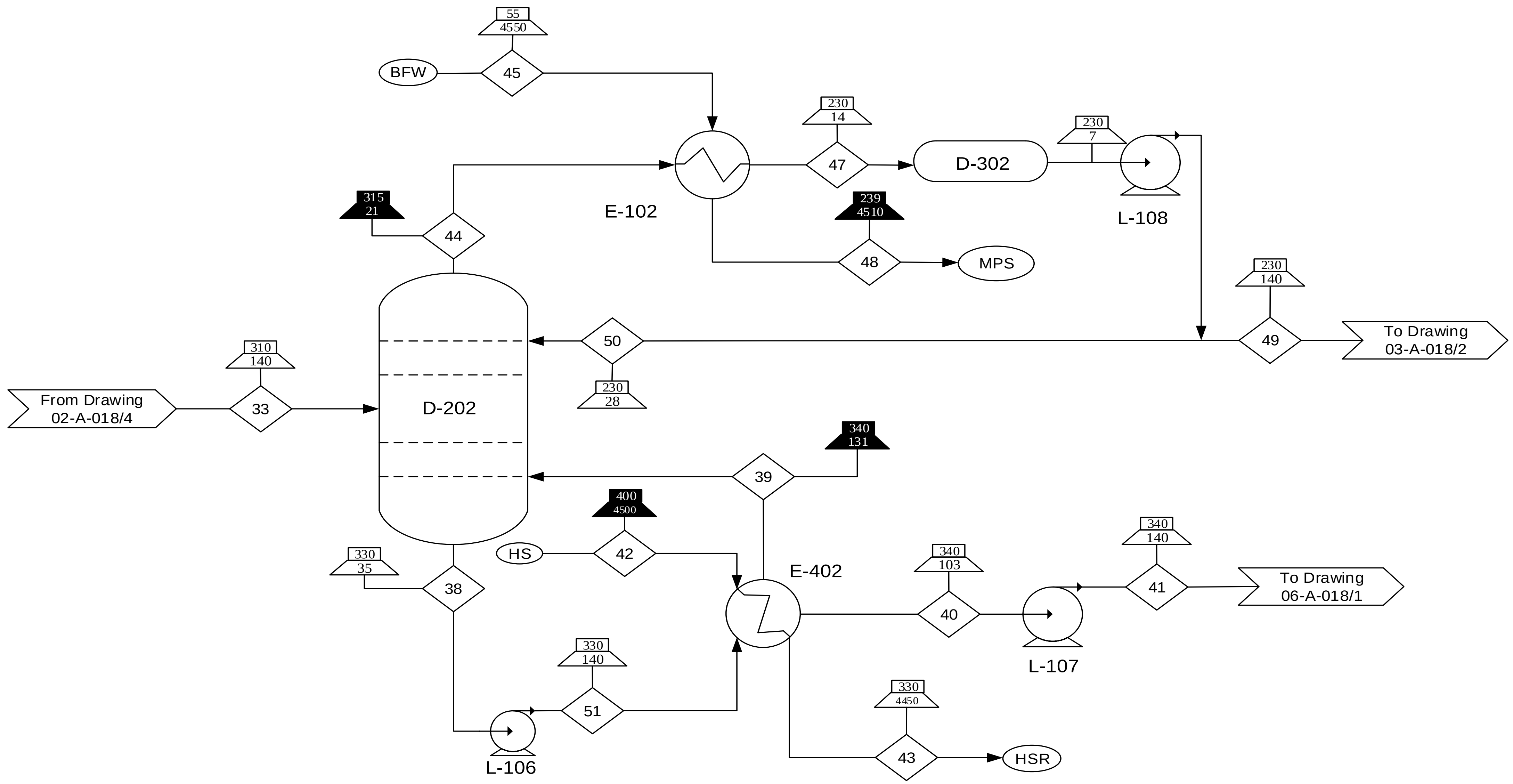
E-402 A/B
Vacuum Column Reboiler
Area= 840 m^2
Duty= 4300 kW

D-302
Vacuum Column Reflux Drum
Length= 5.5 m
Diameter= 1.4 m

L-106 A/B
Vacuum Column Bottoms
Power= 4 kW

L-107 A/B
Vacuum Bottoms
Power= 760 W

L-108 A/B
Vacuum Reflux
Power= 5 kW



Component/Stream (kg/min)	33	38	39	40	41	42	43	44	45	46	47	48	49	50	51
C12-C50	590	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C12-C30	0	0	0	0	0	0	0	770	0	770	770	0	320	430	0
C30-C50	0	1000	730	1000	280	0	0	0	0	0	0	0	0	0	1000
Water	0	0	0	0	0	1500	1500	0	170	0	0	170	0	0	0
Total	590	1000	730	1000	280	1500	1500	770	170	770	770	170	320	430	1000

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
HS High Pressure Steam
HSR High Pressure Steam Condensate
BFW Boiler Feed Water
MPS Medium Pressure Steam

Reference Drawings:
Input/Output Diagrams
00-A-016
Block Flow Diagrams
00-A-017
Process Flow Diagrams
02-A-018
03-A-018
06-A-018

Drawing Type
Process Flow Diagram

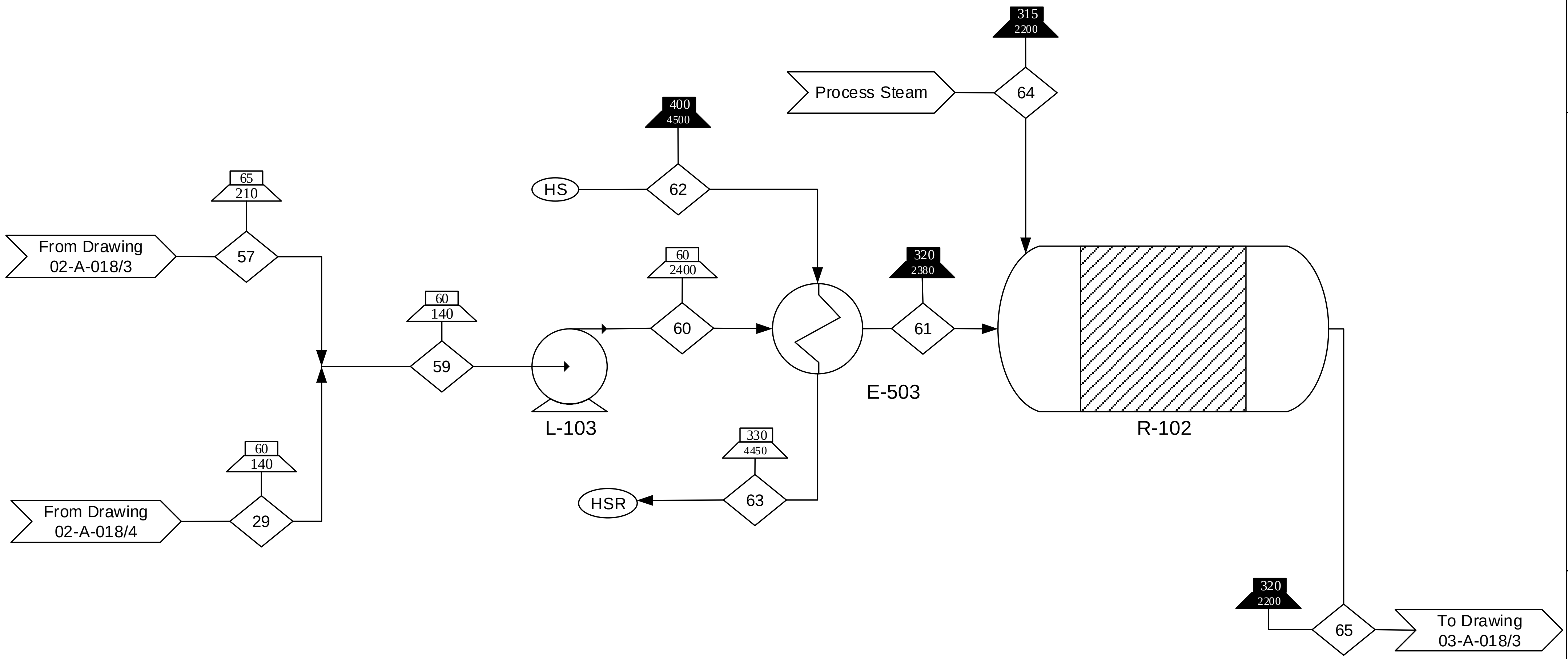
Title
Biorefinery Base Design with Mesophase Pitch- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	02-A-018/5	0

R-102 A/B
Naphtha Decarboxylation Reactor
Diameter= 2.9 m
Length= 17 m
Catalyst= 220 m^3

E-503 A/B
Naphtha Decarbox Heater
Area= 43 m^2
Duty= 3700 kW

L-103 A/B
PreNaphtha Decarbox Pump
Power= 17 kW

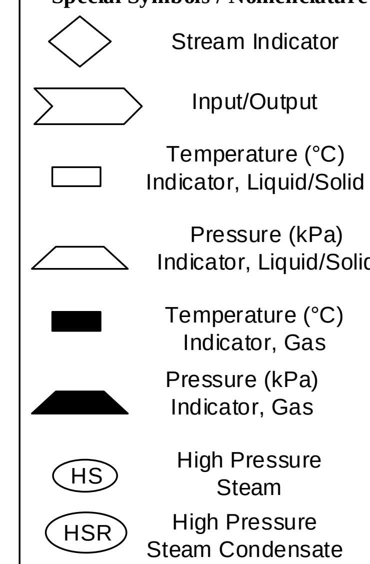


Component/Stream (kg/min)	29	57	59	60	61	62	63	64	65
C6-C8	0	54	0	0	0	0	0	0	0
C7-C12	170	0	0	0	0	0	0	0	0
C6-C12	0	0	220	220	220	0	0	0	0
C1-C12	0	0	0	0	0	0	0	0	230
Water	0	0	0	0	0	1300	1300	7	0
Total	170	54	220	220	220	1300	1300	7	230

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
02-A-018
03-A-018

Drawing Type
Process Flow Diagram

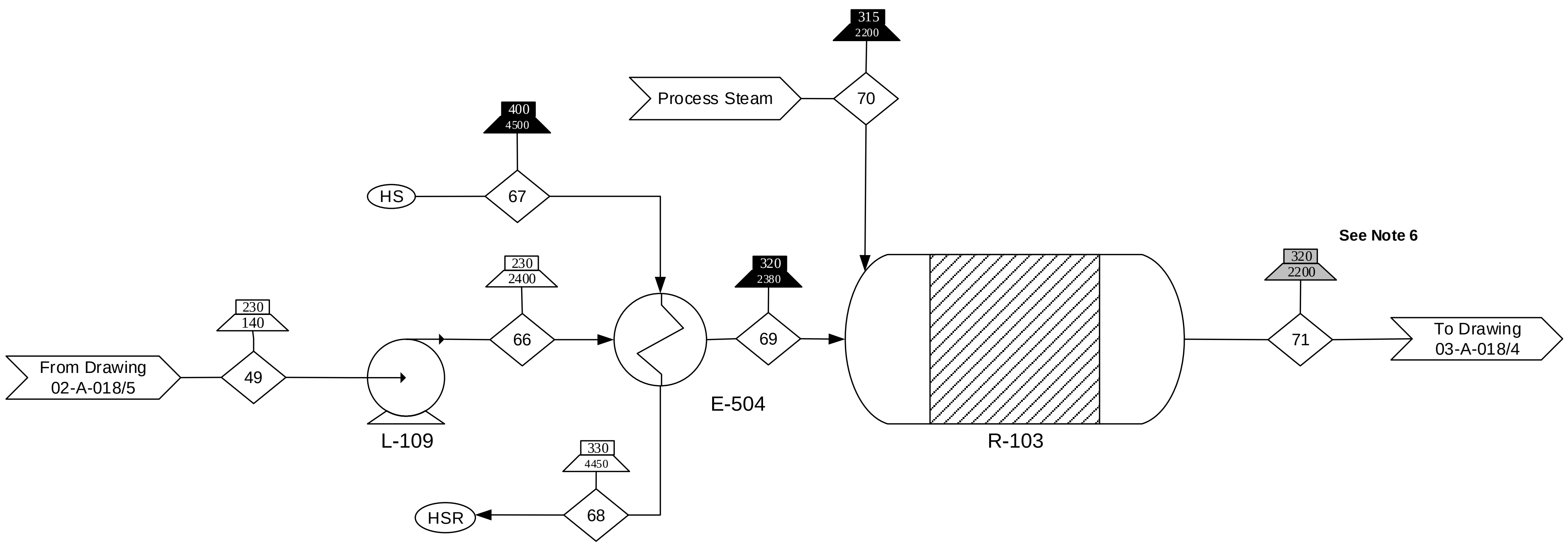
Title
Biorefinery Base Design with Mesophase Pitch – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	03-A-018/1	0

R-103 A/B
Diesel Decarboxylation Reactor
Diameter= 3.2 m
Length= 19 m
Catalyst= 310 m^3

E-504 A/B
Diesel Decarbox Heater
Area= 41 m^2
Duty= 1800 kW

L-109 A/B
Pre Diesel Decarbox Pump
Power= 29 kW



Component/Stream (kg/min)	49	66	67	68	69	70	71
C12-C30	320	320	0	0	320	0	0
C1-C30	0	0	0	0	0	0	330
Water	0	0	640	640	0	10	0
Total	320	320	640	640	320	10	330

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 71 is composed of a liquid gas two phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase
HS High Pressure Steam
HSR High Pressure Steam Condensate

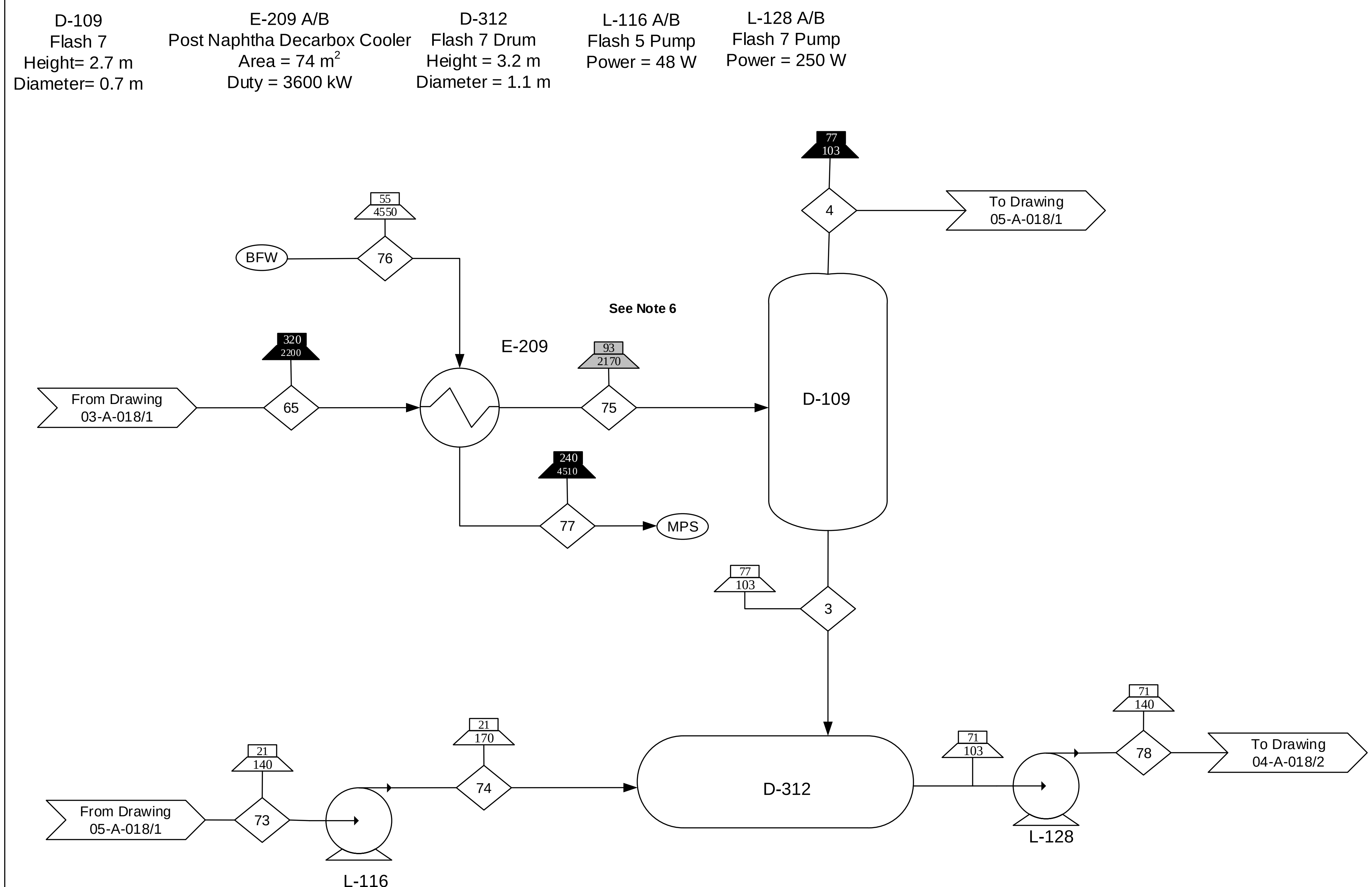
Reference Drawings:

Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
02-A-018
03-A-018

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	03-A-018/2	0



Component/Stream (kg/min)	65	73	74	75	76	77	3	4	78
C1-C12	230	0	0	230	0	0	0	0	0
C6-C9	0	23	23	0	0	0	0	0	200
C1-C4	0	0	0	0	0	0	0	54	0
C4-C12	0	0	0	0	0	0	180	0	0
Water	0	0	0	0	91	91	0	0	0
Total	230	23	23	230	91	91	180	54	200

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 75 is composed of a liquid and gas two phase stream.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- Temperature (°C) Indicator, Two Phase
- Pressure (kPa) Indicator, Two Phase
- MPS Medium Pressure Steam
- BFW Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
03-A-018
04-A-018
05-A-018

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch–Decarboxylation Section

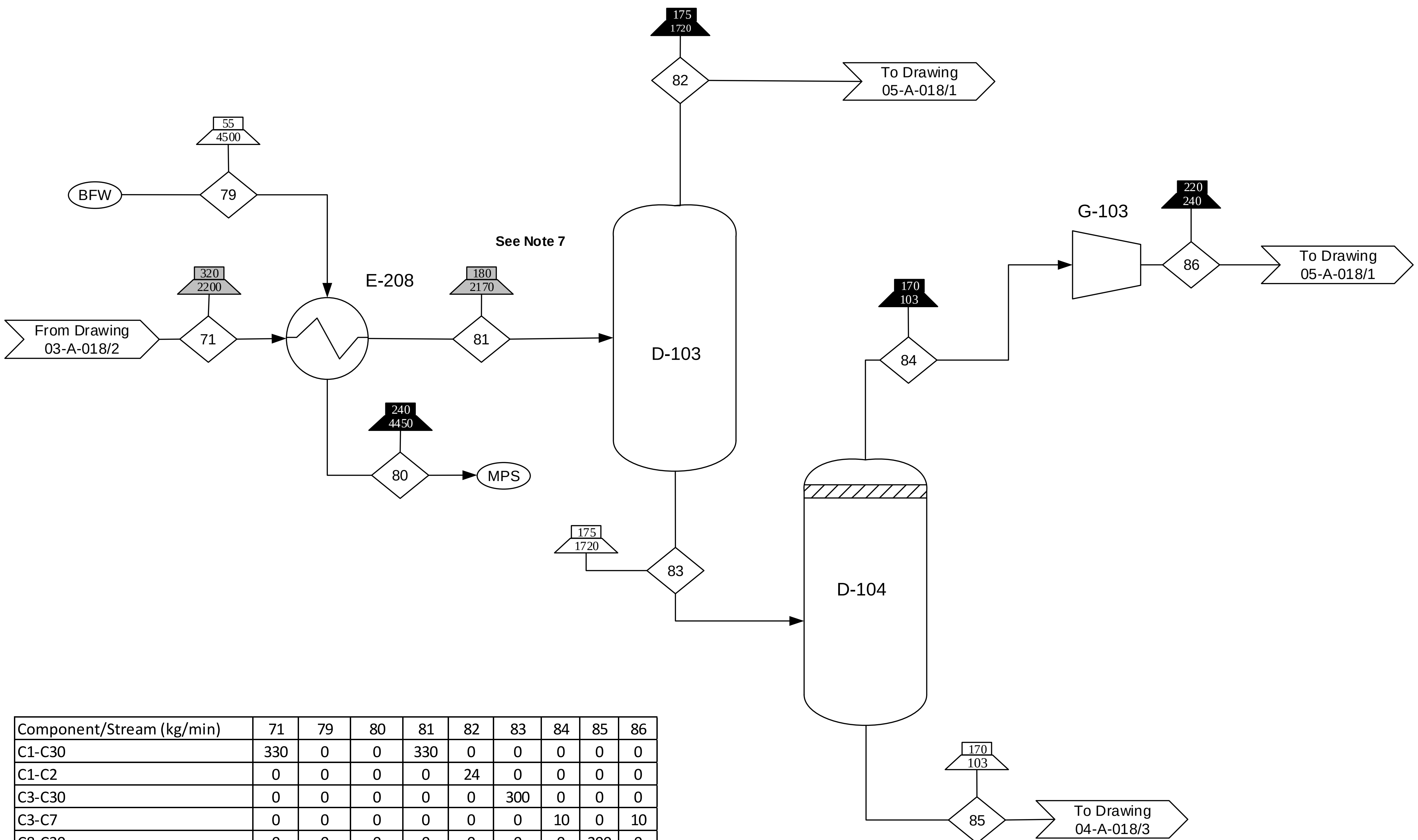
By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	03-A-018/3	0

D-103
Flash 3
Height= 4.9 m
Diameter= 1.2 m

D-104
Flash 4
Height= 4.7 m
Diameter= 1.2 m

E-208 A/B
Post Diesel Decarbox Cooler
Area= 33 m^2
Duty= 2800 kW

G-103 A/B
Flash 5 Compressor
Power= 15 kW

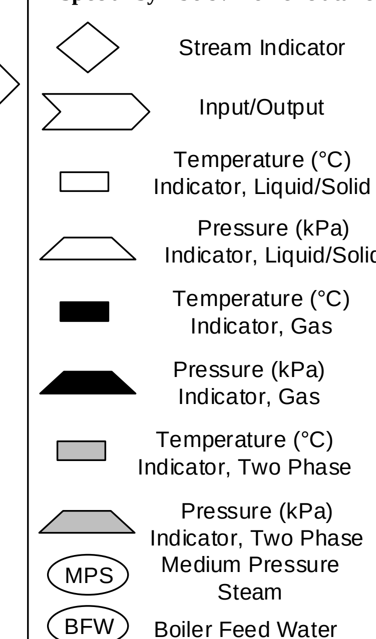


Component/Stream (kg/min)	71	79	80	81	82	83	84	85	86
C1-C30	330	0	0	330	0	0	0	0	0
C1-C2	0	0	0	0	24	0	0	0	0
C3-C30	0	0	0	0	0	300	0	0	0
C3-C7	0	0	0	0	0	0	10	0	10
C8-C30	0	0	0	0	0	0	0	290	0
Water	0	68	68	0	0	0	0	0	0
Total	330	68	68	330	24	300	10	290	10

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
7. Streams 71 and 81 are composed of a liquid and gas two phase stream.

Special Symbols / Nomenclature



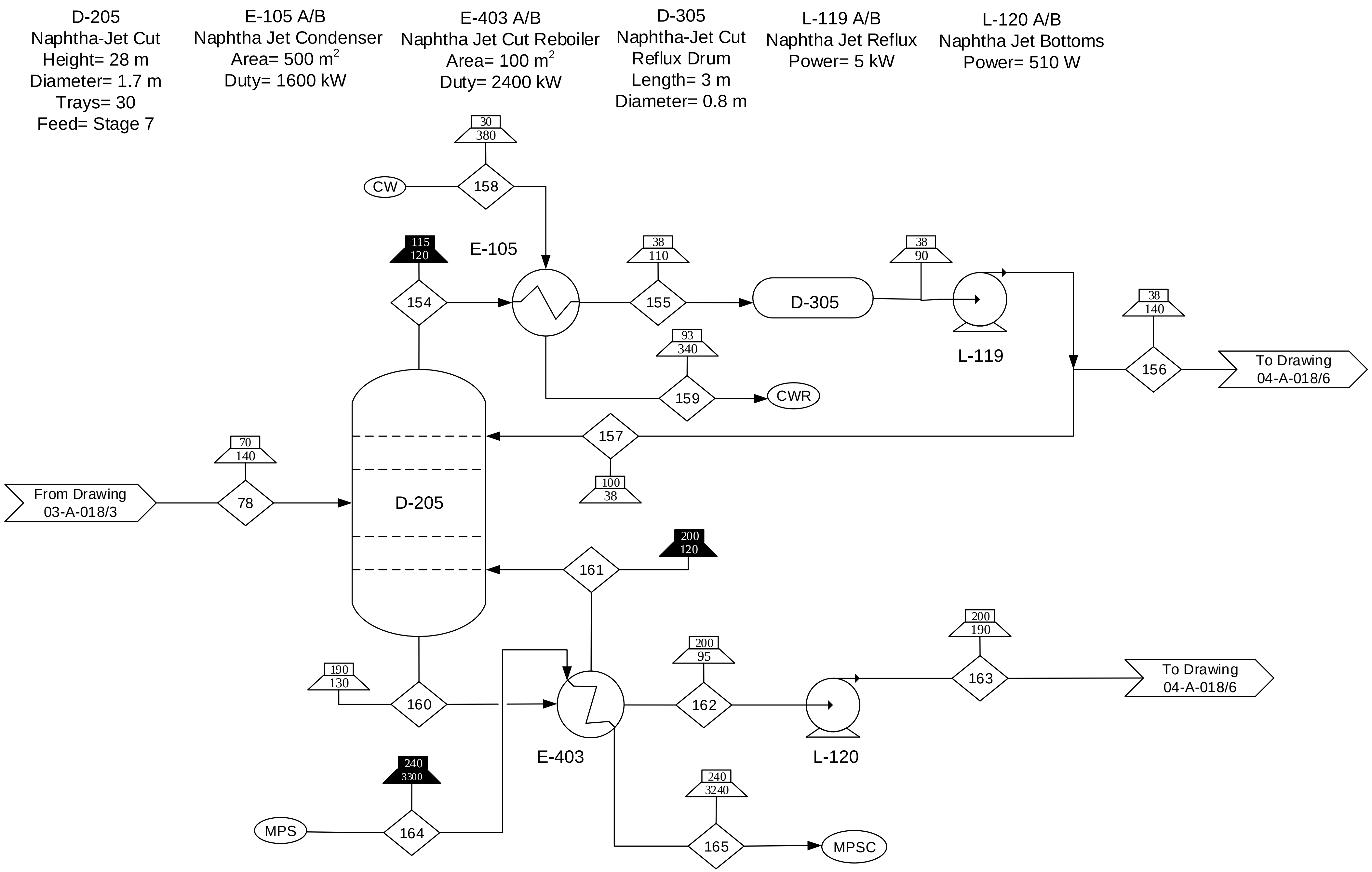
Reference Drawings:

Process Flow Diagrams
03-A-018
04-A-018
05-A-018

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	03-A-018/4	0



Component/Stream (kg/min)	78	154	155	156	157	158	159	160	161	162	163	164	165
C7-C12	200	0	0	0	0	0	0	0	0	0	0	0	0
C7-C9	0	150	150	64	82	0	0	0	0	0	0	0	0
C9-C12	0	0	0	0	0	0	0	330	190	140	140	0	0
Water	0	0	0	0	0	150	150	0	0	0	0	82	82
Total	200	150	150	64	82	150	150	330	190	140	140	82	82

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- MPS: Medium Pressure Steam
- MPSC: Medium Pressure Steam Condensate
- CW: Cooling Water
- CWR: Cooling Water Recycle

Reference Drawings:

Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
03-A-018
04-A-018

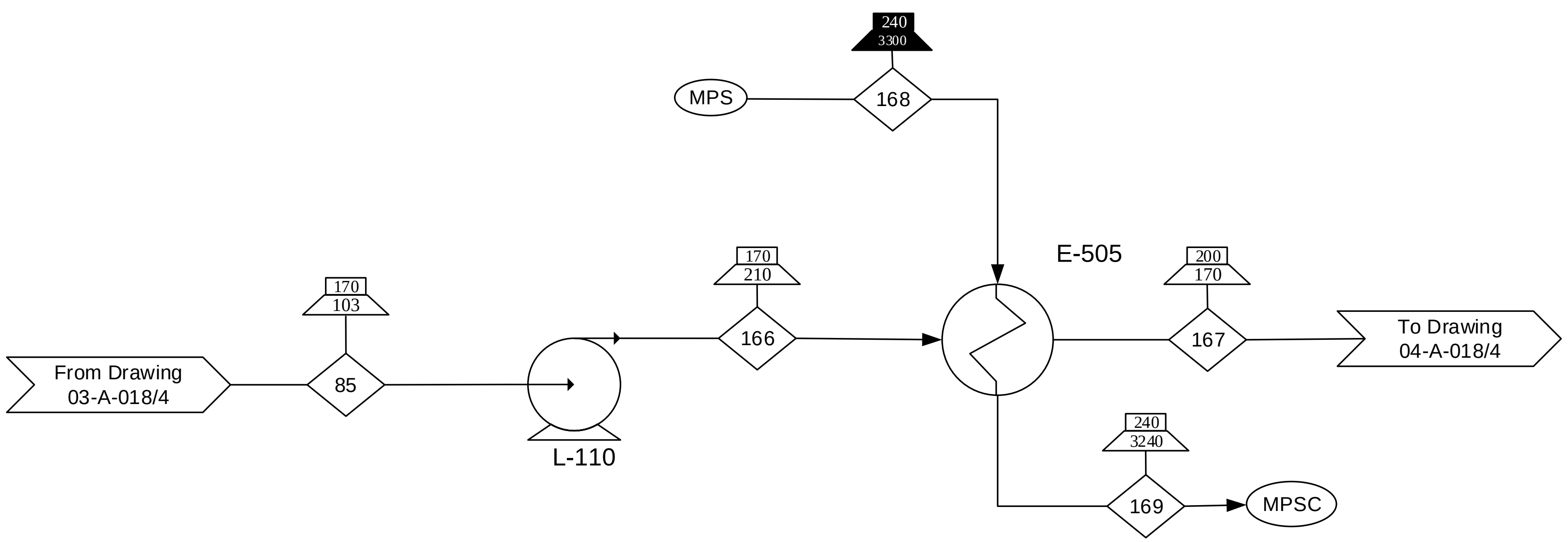
Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	04-A-018/2	0

E-505 A/B
Pre Jet Diesel Cut Heat
Area = 22 m^2
Duty = 540 kW

L-110 A/B
Pre Jet Diesel Cut Heat Pump
Power = 1 kW



Component/Stream (kg/min)	85	166	167	168	169
C8-C30	290	290	290	0	0
Water	0	0	0	18	18
Total	290	290	290	18	18

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- MPS — Medium Pressure Steam
- MPSC — Medium Pressure Steam Condensate

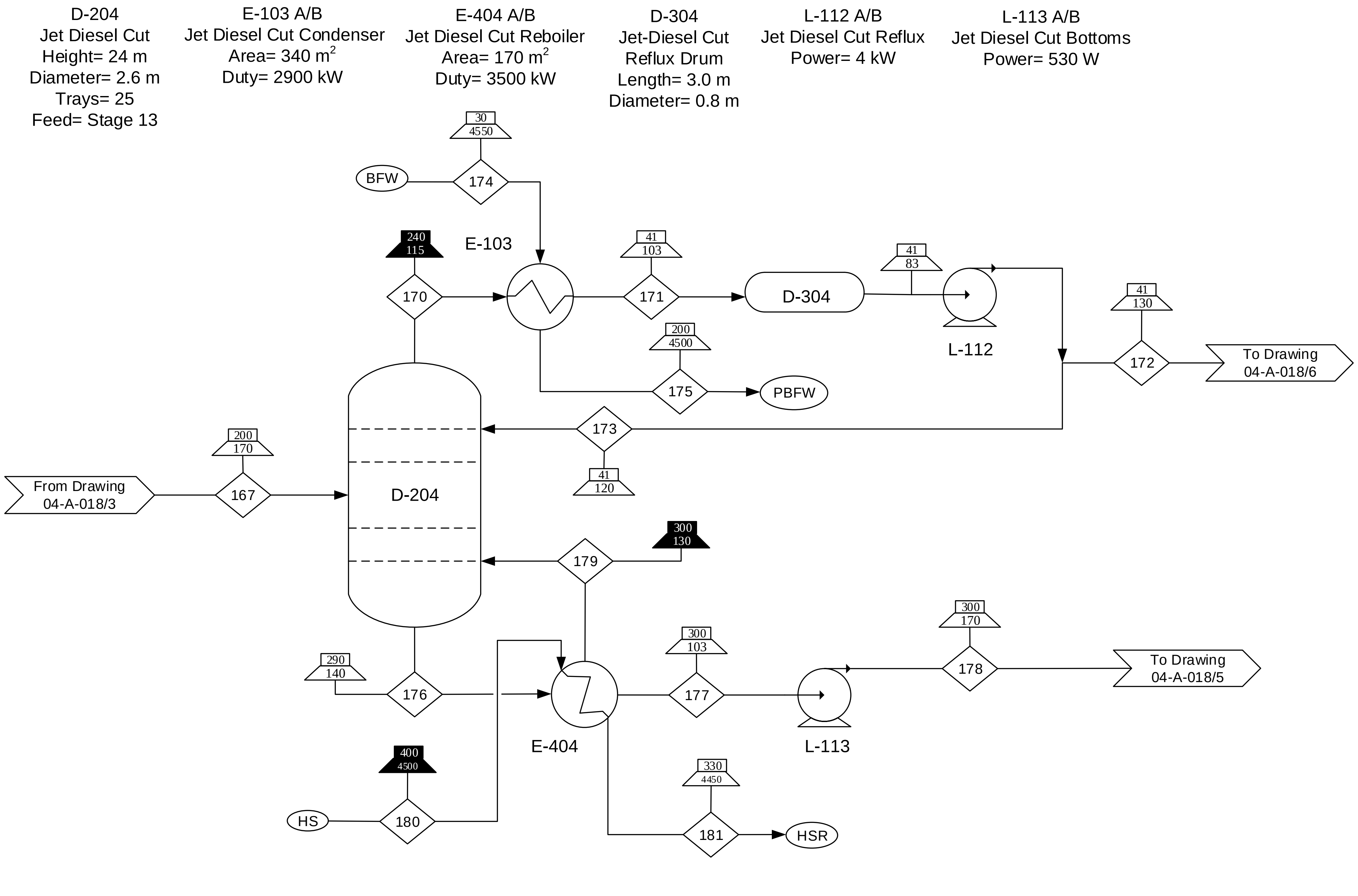
Reference Drawings:

Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
03-A-018
04-A-018

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	04-A-018/3	0



Component/Stream (kg/min)	167	170	171	172	173	174	175	176	177	178	179	180	181
C8-C30	290	0	0	0	0	0	0	0	0	0	0	0	0
C8-C15	0	190	190	73	110	0	0	0	0	0	0	0	0
C16-C30	0	0	0	0	0	0	0	860	220	200	640	0	0
Water	0	0	0	0	0	89	89	0	0	0	0	1200	1200
Total	290	190	190	73	110	89	89	860	220	220	640	1200	1200

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°C) Indicator, Liquid/Solid

Pressure (kPa) Indicator, Liquid/Solid

Temperature (°C) Indicator, Gas

Pressure (kPa) Indicator, Gas

HS High Pressure Steam

HSR High Pressure Steam Condensate

BFW Boiler Feed Water

PBFW Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagam
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
04-A-018

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	04-A-018/4	0

D-206
Diesel Fuel Oil Cut
Height= 37 m
Diameter= 2.8 m
Trays= 40
Feed= Stage 28

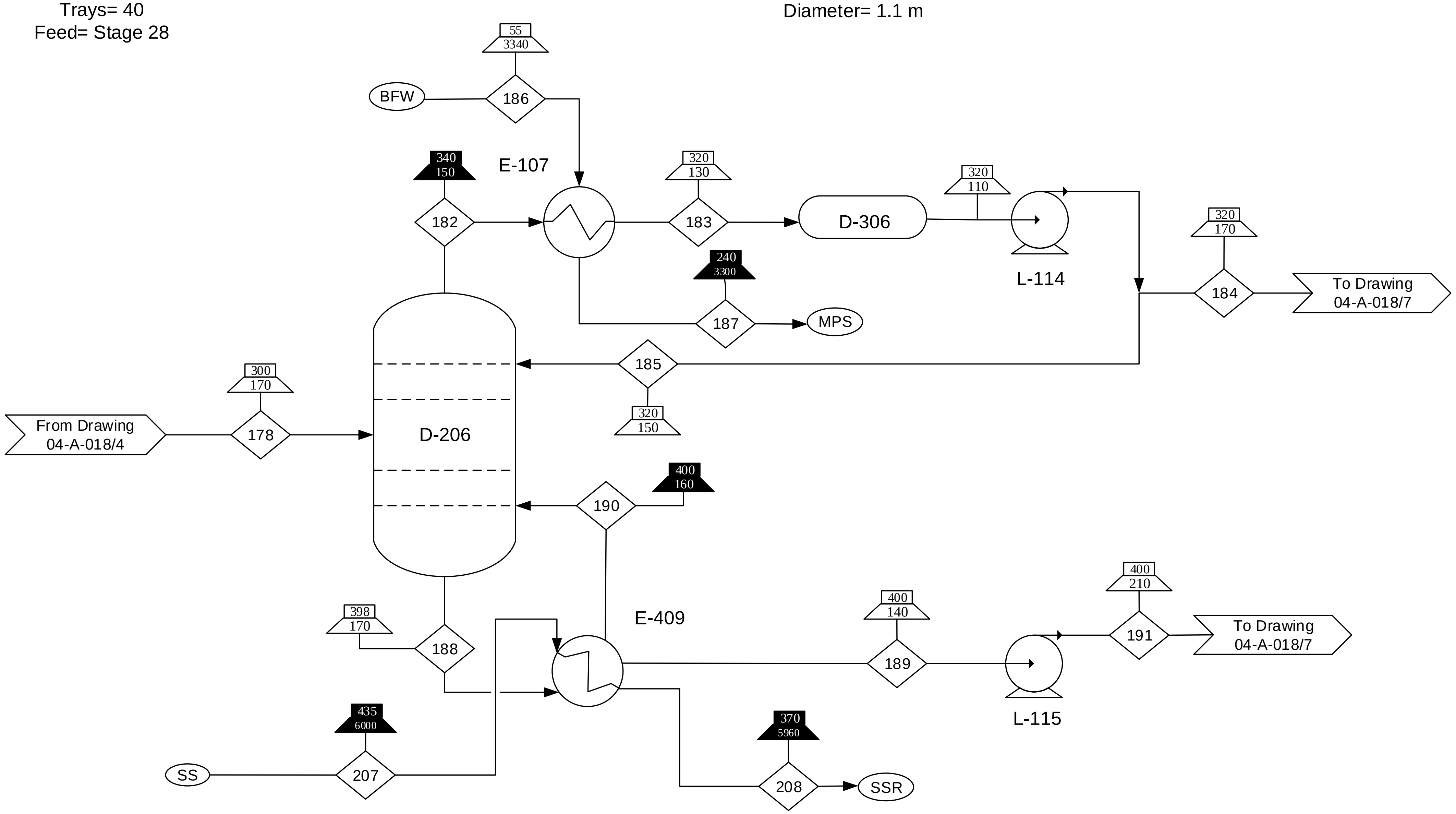
E-409 A/B
Diesel Fuel Oil Cut Reboiler
Area= 200 m^2
Duty= 2200 kW

E-107 A/B
Diesel Fuel Oil Cut Condenser
Area= 15 m^2
Duty= 2200 kW

D-306
Diesel Fuel Oil Cut
Reflux Drum
Length= 4.3 m
Diameter= 1.1 m

L-114 A/B
Diesel Fuel Oil Cut Reflux
Power= 7 kW

L-115 A/B
Diesel Fuel Oil Cut Bottoms
Power= 31 W



Component/Stream (kg/min)	178	182	183	184	185	186	187	188	189	190	191	207	208
C16-C30	220	0	0	0	0	0	0	0	0	0	0	0	0
C16-C21	0	380	380	210	160	0	0	0	0	0	0	0	0
C22-C30	0	0	0	0	0	0	0	640	5	640	4	0	0
Water	0	0	0	0	0	54	54	0	0	0	0	760	760
Total	220	380	380	210	160	54	54	640	5	640	4	760	760

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
MPS Medium Pressure Steam
BFW Boiler Feed Water
SS Superheated Steam
SSR Superheated Steam Recycle

Reference Drawings:

Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
04-A-018

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Trim Purification Section

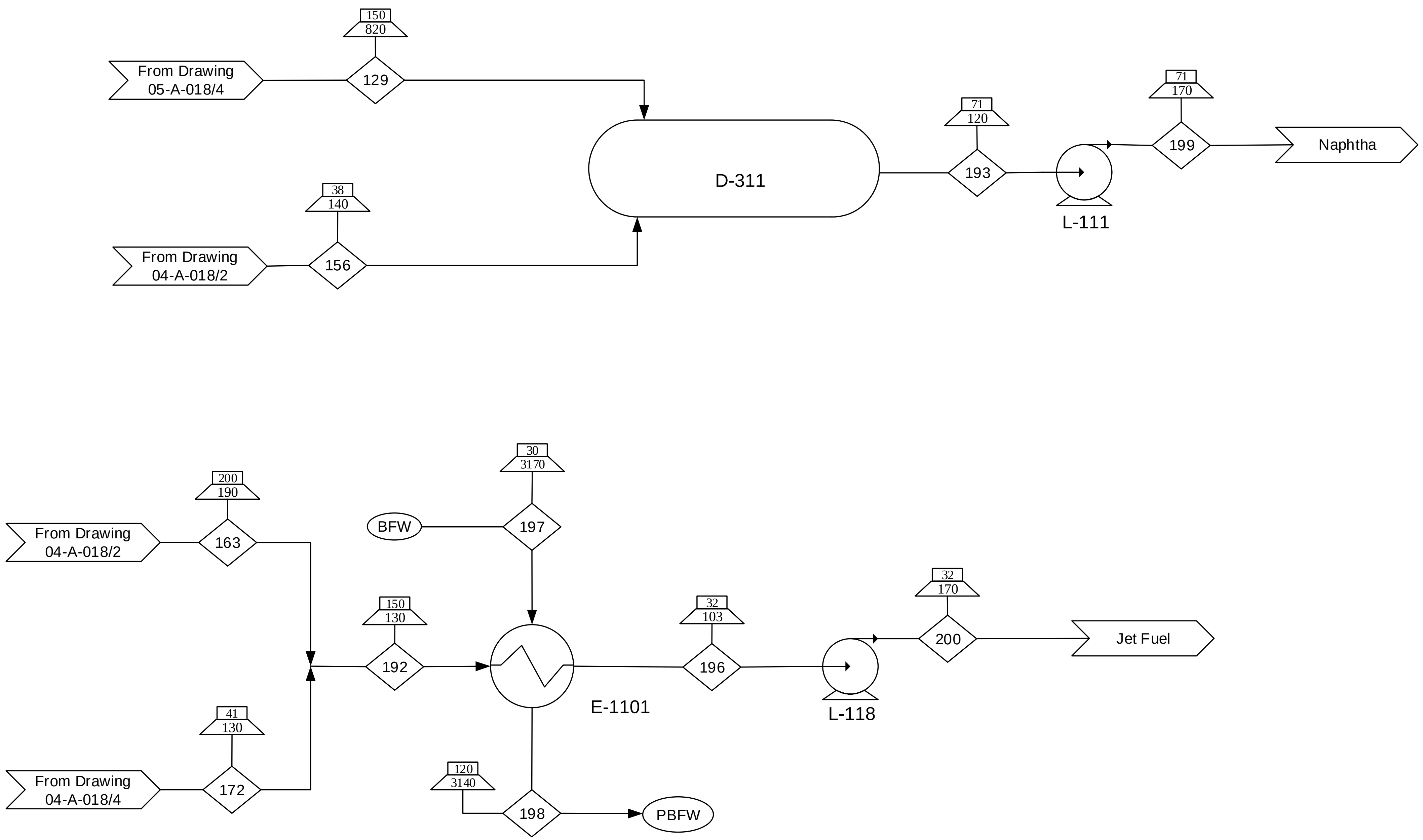
By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	04-A-018/5	0

D-311
Naphtha Drum
Height = 3.7 m
Diameter = 0.9 m

E-1101 A/B
Jet Cooler
Area = 260 m^2
Duty = 1200 kW

L-111 A/B
Naphtha Product
Power = 200 W

L-118 A/B
Jet Fuel Product
Power = 540 W



Component/Stream (kg/min)	129	156	163	172	192	193	196	197	198	199	200
Naphtha Product	64	64	0	0	0	130	0	0	0	130	0
Jet Fuel Product	0	0	140	73	210	0	210	0	0	0	210
Water	0	0	0	0	0	0	0	110	110	0	0
Total	64	64	140	73	210	130	210	110	110	130	210

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- BFW Boiler Feed Water
- PBFW Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
04-A-018
05-A-018

Drawing Type
Process Flow Diagram

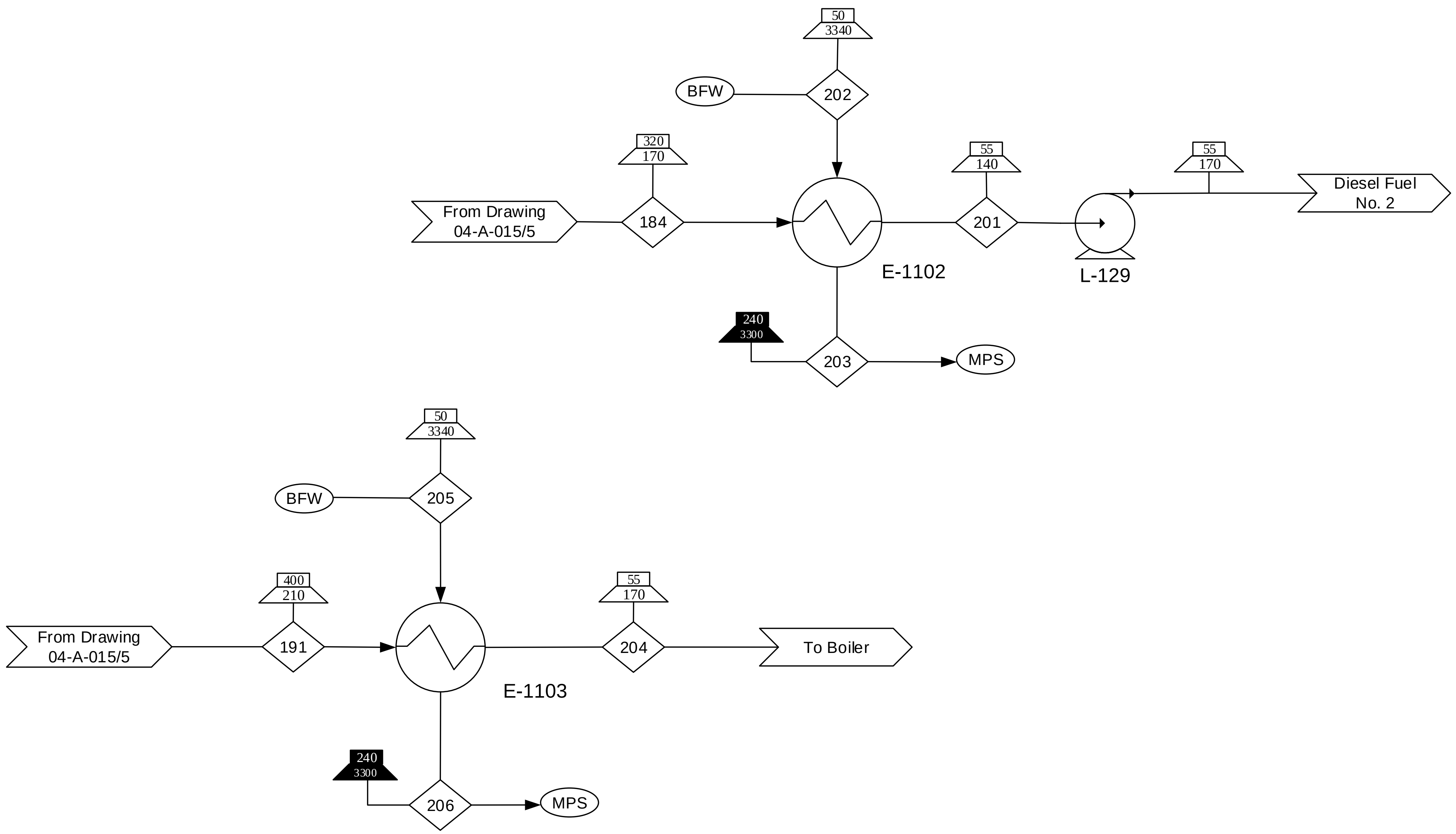
Title
Biorefinery Base Design with Mesophase Pitch – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	04-A-018/6	0

E-1102 A/B
Diesel Cooler
Area = 130 m^2
Duty = 3000 kW

E-1103 A/B
Fuel Oil Cooler
Area = 6 m^2
Duty = 80 kW

L-129 A/B
Diesel Product
Power = 330 W



Component/Stream (kg/min)	184	191	201	202	203	204	205	206
Diesel Fuel No. 2 Product	210	0	210	0	0	0	0	0
Fuel Oil No. 5 Product	0	4	0	0	0	4	0	0
Water	0	0	0	73	73	0	2	2
Total	210	4	210	73	73	4	2	2

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
MPS Medium Pressure Steam
BFW Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
04-A-018

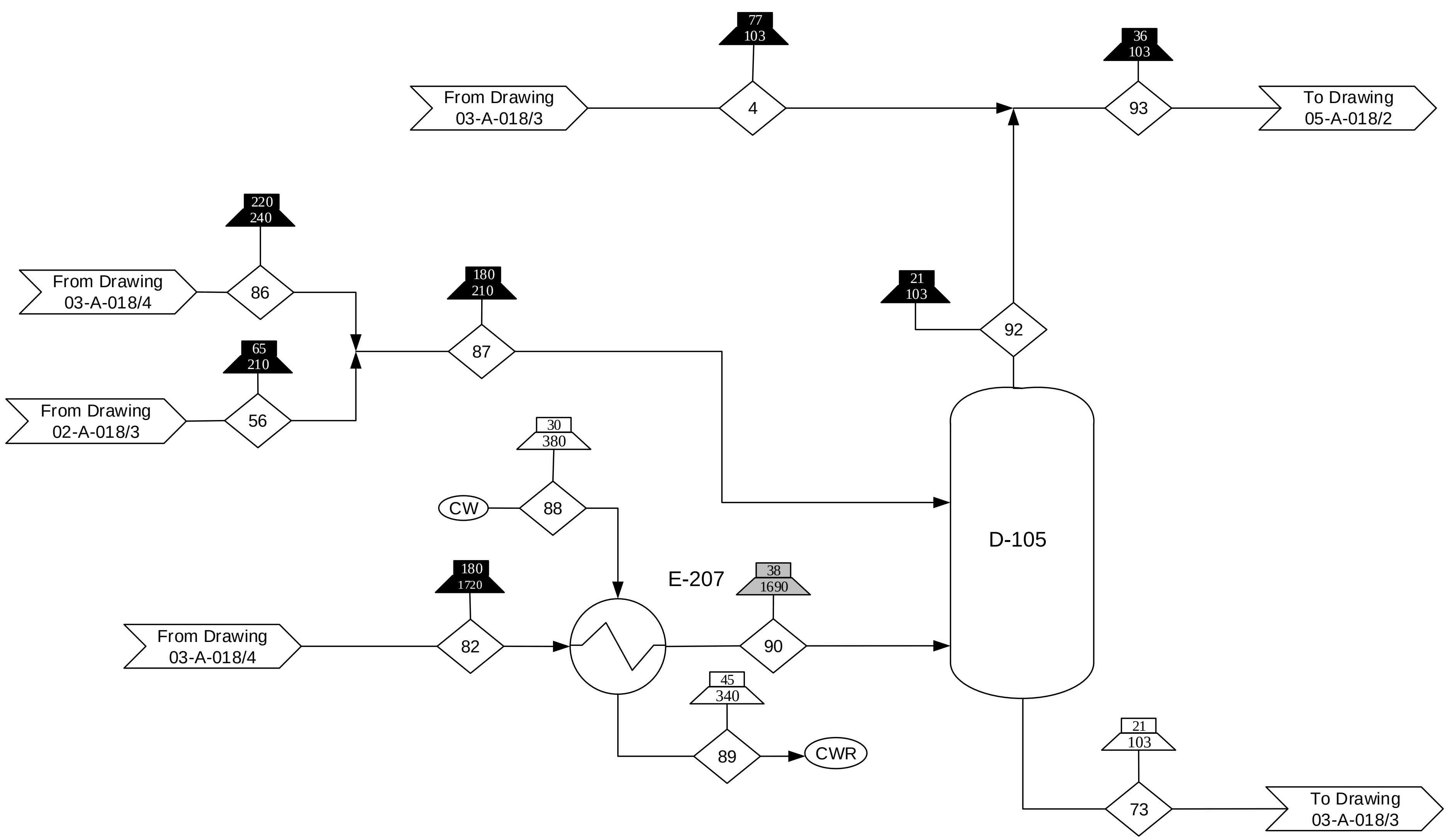
Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	04-A-018/7	0

D-105
Flash 5
Height= 5.4 m
Diameter= 1.4 m

E-207 A/B
Pre-Flash 5 Cooler
Area= 41 m^2
Duty= 400 kW



Component/Stream (kg/min)	4	56	73	82	86	87	88	89	90	92	93
C1-C2	0	0	0	24	0	0	0	0	24	0	0
C3-C7	0	0	0	0	10	0	0	0	0	0	0
C1-C7	0	0	0	0	0	0	0	0	0	0	0
C1-C6	54	170	0	0	0	180	0	0	0	190	240
C6-C7	0	0	23	0	0	0	0	0	0	0	0
Water	0	0	0	0	0	0	38	38	0	0	0
Total	54	170	23	24	10	180	38	38	24	190	240

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- Temperature (°C) Indicator, Two Phase
- Pressure (kPa) Indicator, Two Phase
- CW Cooling Water
- CWR Cooling Water Recycle

Reference Drawings:

Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
02-A-018
03-A-018
05-A-018

Drawing Type
Process Flow Diagram

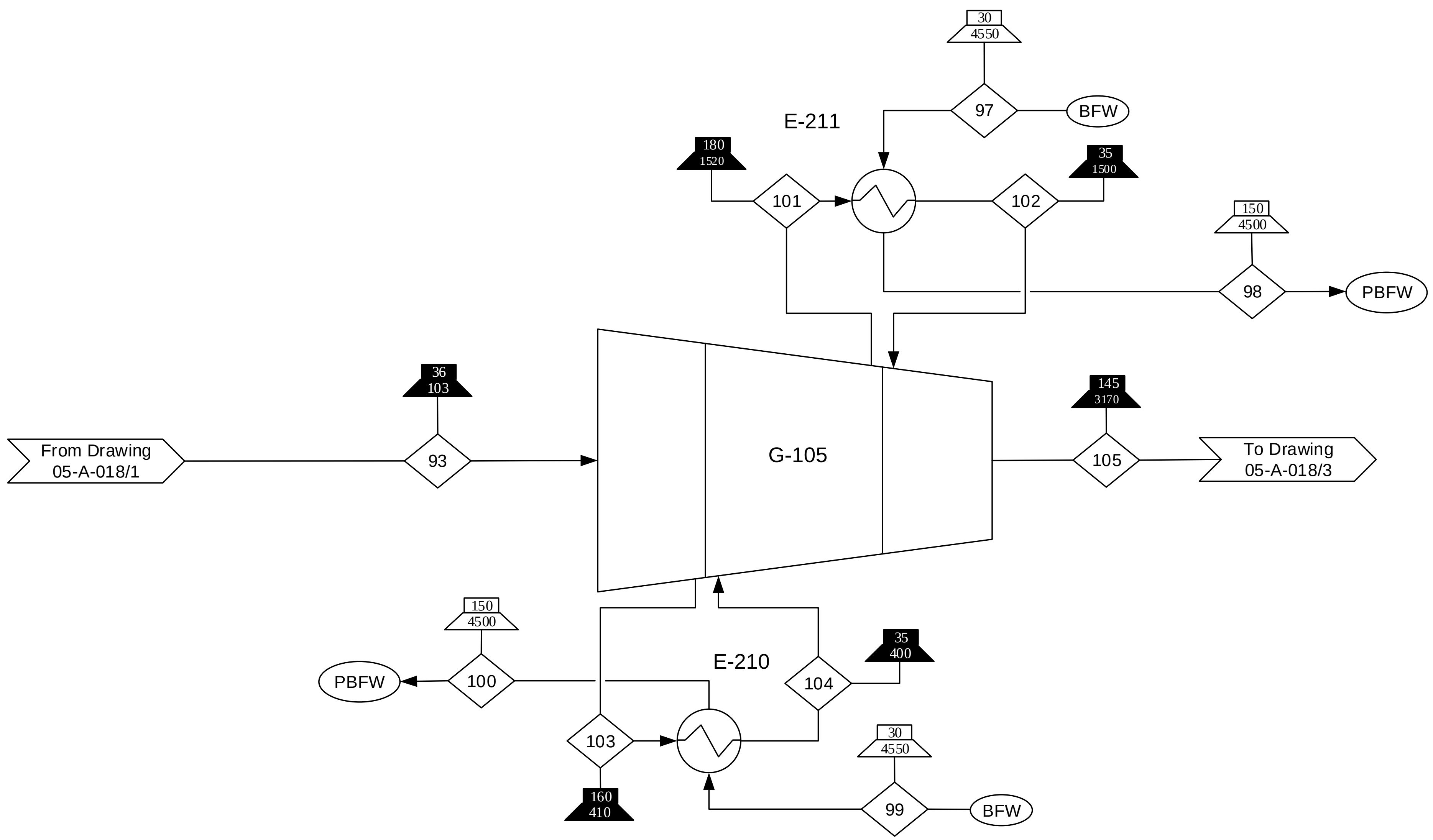
Title
Biorefinery Base Design with Mesophase Pitch – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	05-A-018/1	0

G-105
Light End Compressor
3 Stages
Stage 1 Power= 630 kW
Stage 2 Power = 630 kW
Stage 3 Power = 630 kW

E-210 A/B
Interstage Cooler 1
Area= 210 m^2
Duty= 750 kW

E-211 A/B
Interstage Cooler 2
Area= 130 m^2
Duty= 890 kW



Component/Stream (kg/min)	93	97	98	99	100	101	102	103	104
C1-C6	240	0	0	0	0	240	240	240	240
Water	0	83	83	69	69	0	0	0	0
Total	240	83	83	69	69	240	240	240	240

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

5. Compressors operate at 55% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°C) Indicator, Liquid/Solid

Pressure (kPa) Indicator, Liquid/Solid

Temperature (°C) Indicator, Gas

Pressure (kPa) Indicator, Gas

BFW Boiler Feed Water

PBFW Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
05-A-018

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	05-A-018/2	0

D-207
Syngas Column
Height= 37 m
Diameter= 2.7 m
Trays= 40
Feed= Stage 5

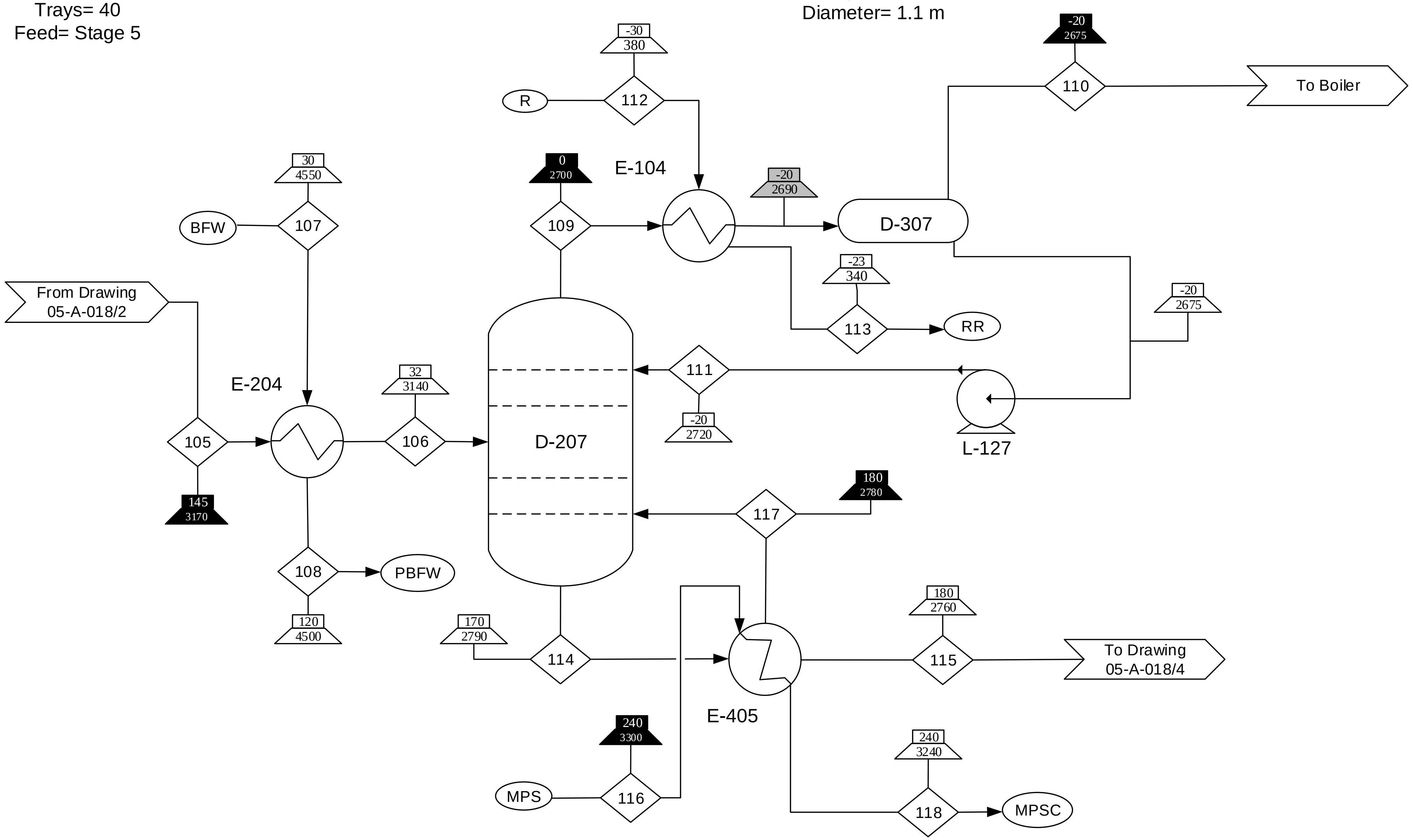
E-204 A/B
Syngas Cooler
Area= 360 m^2
Duty= 1400 kW

E-104 A/B
Syngas Condenser
Area= 75 m^2
Duty= 580 kW

E-405 A/B
Syngas Reboiler
Area= 19 m^2
Duty= 1000 kW

D-307
Syngas Column
Reflux Drum
Length= 4.3 m
Diameter= 1.1 m

L-127 A/B
Syngas Column Reflux
Power= 6 kW



Component/Stream (kg/min)	105	106	107	108	109	110	111	112	113	114	115	116	117	118
C1-C6	240	240	0	0	0	0	0	0	0	0	0	0	0	0
C1-C3	0	0	0	0	240	160	77	0	0	0	0	0	0	0
C4-C6	0	0	0	0	0	0	0	0	0	350	82	0	270	0
Water	0	0	130	130	0	0	0	540	540	0	0	34	0	34
Total	240	240	130	130	240	160	77	540	540	350	82	34	270	34

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- Temperature (°C) Indicator, Two Phase
- Pressure (kPa) Indicator, Two Phase
- MPS — Medium Pressure Steam
- MPSC — Medium Pressure Steam Condensate
- R — Refrigerant
- RR — Refrigerant Return
- BFW — Boiler Feed Water
- PBFW — Preheated Boiler Feed Water

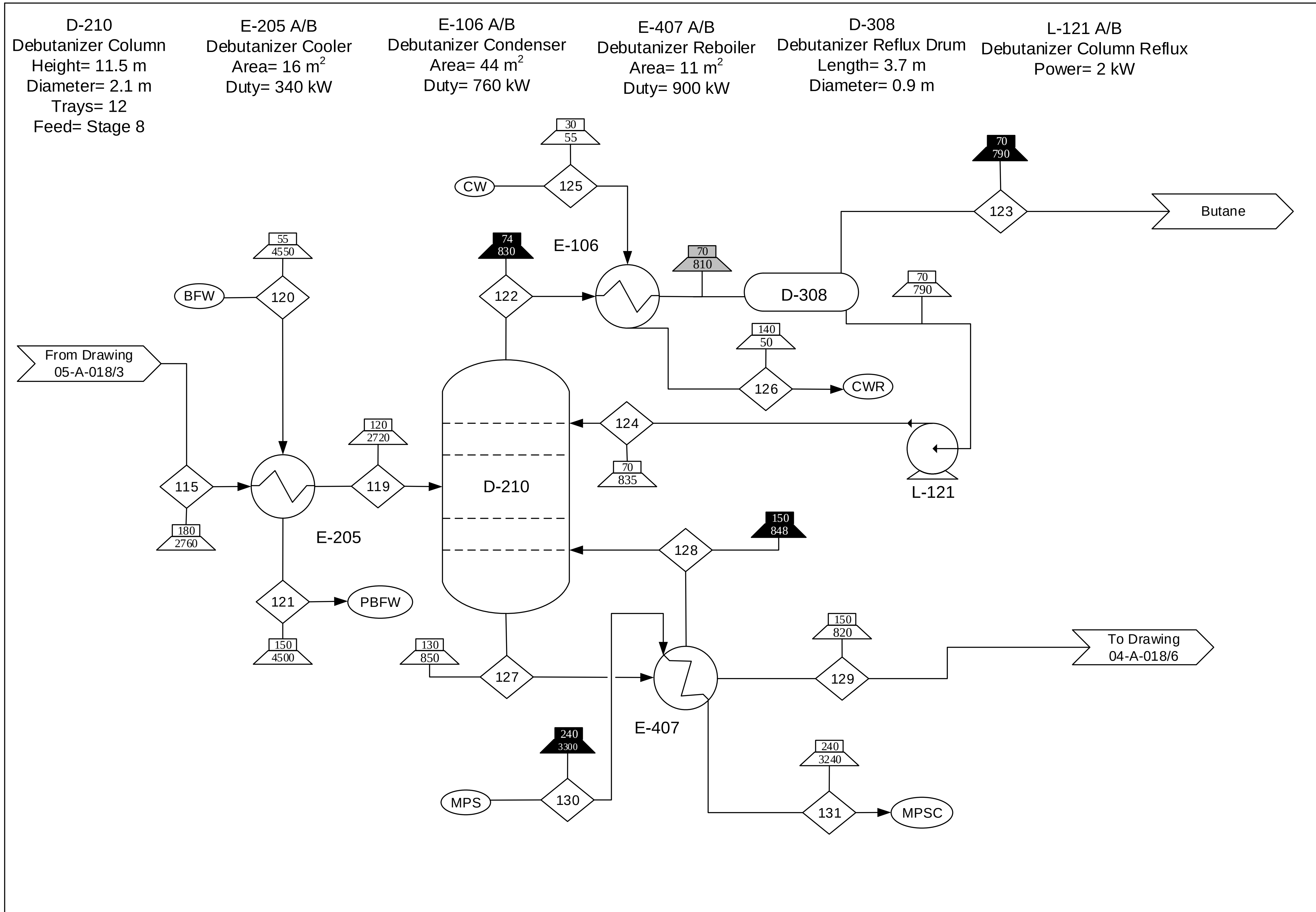
Reference Drawings:

Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
05-A-018

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	05-A-018/3	0



Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

5. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- Temperature (°C) Indicator, Two Phase
- Pressure (kPa) Indicator, Two Phase
- MPS Medium Pressure Steam
- MPSC Medium Pressure Steam Condensate
- CW Cooling Water
- CWR Cooling Water Recycle
- BFW Boiler Feed Water
- PBFW Preheated Boiler Feed Water

Reference Drawings:

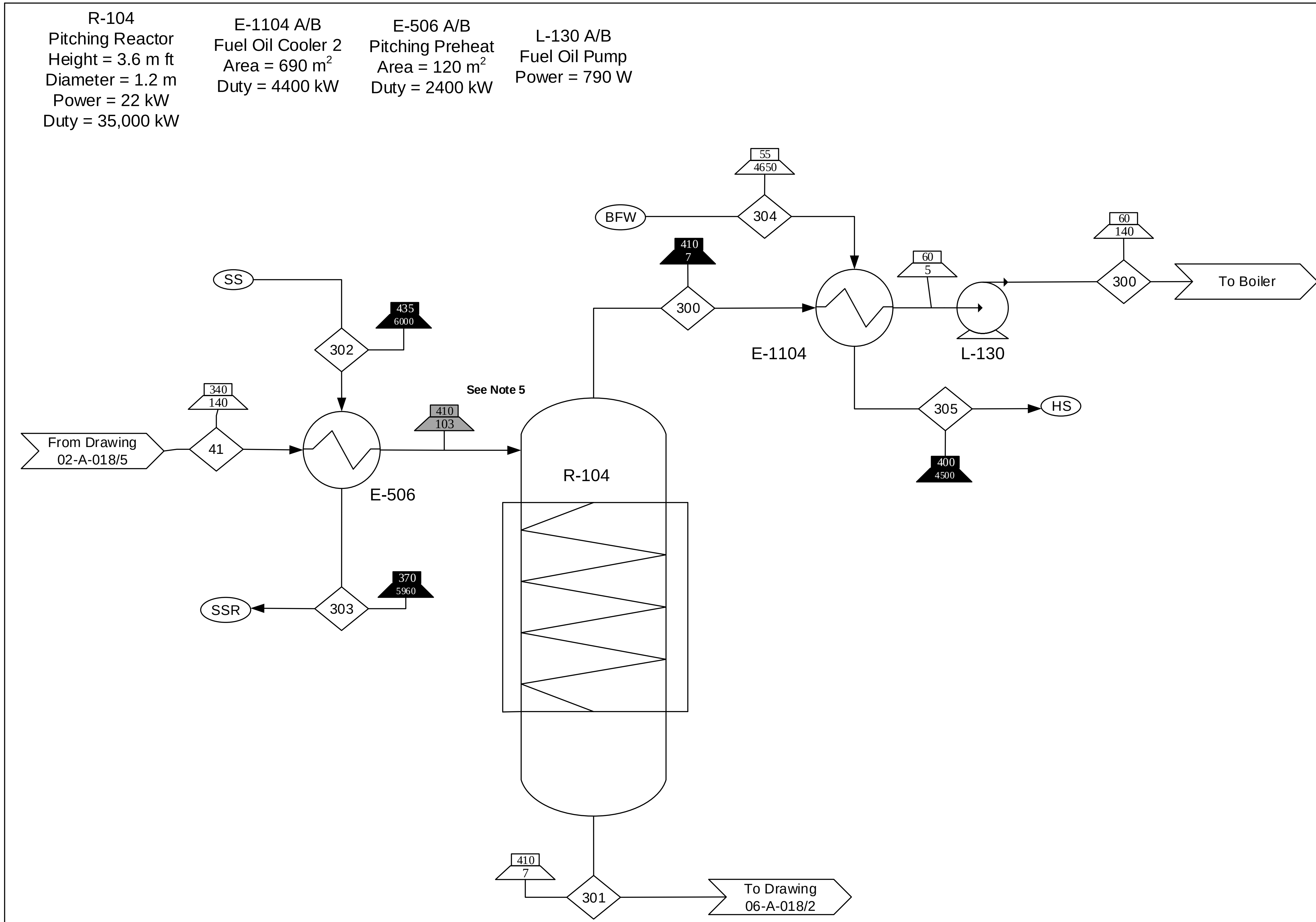
Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
04-A-018
05-A-018

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	05-A-018/4	0

Component/Stream (kg/min)	115	119	120	121	122	123	124	125	126	127	128	129	130	131
C4-C6	82	82	0	0	0	0	0	0	0	0	0	0	0	0
Butane	0	0	0	0	150	21	130	0	0	0	0	0	0	0
C5-C6	0	0	0	0	0	0	0	0	0	230	160	64	0	0
Water	0	0	32	32	0	0	0	70	70	0	0	0	31	31
Total	82	82	32	32	150	21	130	70	70	230	160	64	31	31



Component/Stream (kg/min)	41	300	301	302	303	304	305
C30-C50	280	0	0	0	0	0	0
Fuel Oil No. 5 Product	0	180	0	0	0	0	0
Mesophase Pitch	0	0	100	0	0	0	0
Water	0	0	0	810	810	110	110
Total	280	180	100	810	810	110	110

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

5. Stream 41 goes into the pitching reactor as a gas and liquid two-phase stream.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°C) Indicator, Liquid/Solid

Pressure (kPa) Indicator, Liquid/Solid

Temperature (°C) Indicator, Gas

Pressure (kPa) Indicator, Gas

Temperature (°C) Indicator, Two Phase

Pressure (kPa) Indicator, Two Phase

HS High Pressure Steam

BFW Boiler Feed Water

SS Superheated Steam

SSR Superheated Steam Recycle

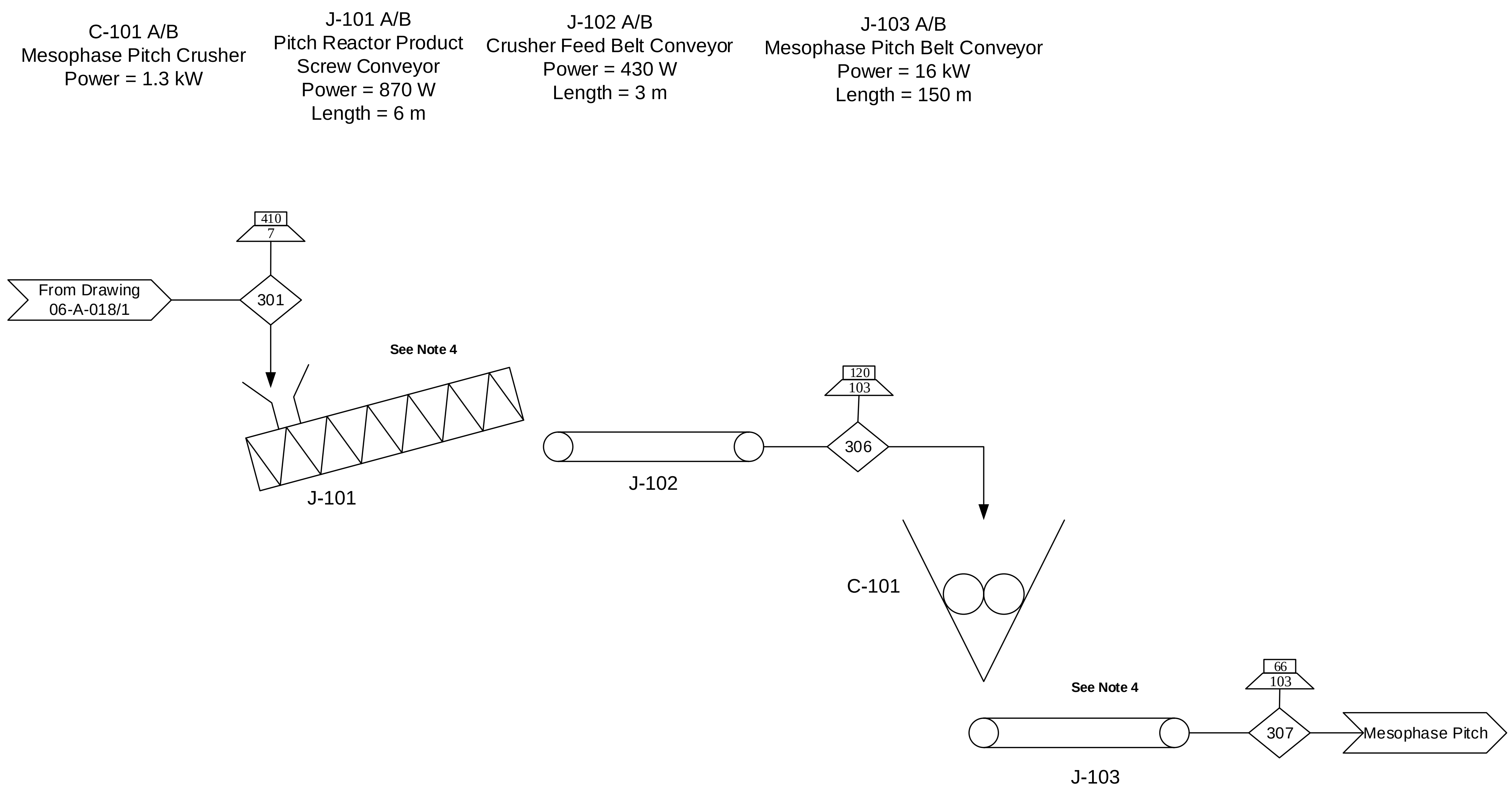
Reference Drawings:

Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
02-A-018
06-A-018

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Heavy End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	06-A-018/1	0



Component/Stream (lb/min)	301	306	307
Mesophase Pitch	100	100	100
Total	100	100	100

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Screw and conveyor are uninsulated, so pitch returns to ambient temperatures slowly.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°C) Indicator, Liquid/Solid

Pressure (kPa) Indicator, Liquid/Solid

Reference Drawings:

Input/Output Diagram
00-A-016
Block Flow Diagram
00-A-017
Process Flow Diagrams
02-A-018
06-A-018

Drawing Type

Process Flow Diagram

Title

Biorefinery Base Design with Mesophase Pitch – Heavy End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	06-A-018/2	0

Chapter VI

ALTERNATIVE COMPARISON AND CROP OIL INTEGRATION

Chapters III, IV, and V of this thesis provide preliminary designs and economic assessments on the three alternative biorefineries developed. Comparing these alternatives both qualitively and quantitivley will help to determine the positives and negatives associated with each alternative. Section VI.A. of this chapter compares these three alternatives on the levels of economics, maintainability, operatibiity, sustainability, environmental impact, and safety.

Section VI.B. of this chapter then integrates each alternative with a previously developed soybean oil processing plant. This integration helps to determine how feasible it would be to combine the noncatalytic cracking biorefineries with crop oil processing plants.

VI.A. Comparison of TAG Oil Biorefinery Alternatives

Chapter III of this thesis provided the preliminary design and economic assessment of the base design of a biorefinery based on the noncatalytic cracking of TAG oils. This design includes the production of transportation fuels and limited byproducts, without the production of any additional byproducts that reduce the quantity of fuel products. This design required a total capital investment of \$130 million ± 40%, and produced a NPV @12% of \$(820 million) ± 40% over a 20 year lifecycle.

In order to make the process more economically feasible, the development of a process that produces more profitable byproducts was performed in Chapter IV.

Production of these additional high value byproducts can help reduce the economic risk surrounding the production of transportation fuels from triglyceride based oils. This alternative extracted and recovered the short and medium chain fatty acids that were produced during the cracking reactions. This alternative required a total capital investment of $120 million ± 40%, and produced a NPV@12% of $340 million ± 40% over a 20 year lifecycle.

Although the development of the fatty acid recovery alternative provided a biorefinery that was profitable over the lifecycle, an additional alternative that processed the vacuum bottoms produced within the base alternative was performed. This design, shown in Chapter V, processed the vacuum bottoms into the lucrative byproduct of mesophase pitch, while still producing significant quantities of transportation fuels. This design required a TCI of $140 million ± 40%, and produces a NPV@12% of $1.4 billion ± 40% over a 20 year life cycle.

From an economic standpoint it is clear that the base alternative without heavy end processing is not feasible at the current product and soybean oil raw material prices. The remaining two alternatives were compared with an incremental net profit analysis, shown in Table 103, to determine how much more profitable the mesophase pitch recovery design is compared to the fatty acid recovery design. As seen from this analysis, the mesophase pitch recovery design is more profitable over the 20 year lifecycle by $1 billion ± 40%.

Table 103. Incremental net profit analysis at a hurdle rate of 12%.

	Net Profit			
Year	Mesophase Pitch Recovery	Fatty Acid Recovery	(Mesophase Pitch - Fatty Acid)	PV@HR
-1	($54,000)	($51,000)	($2,700)	($3,000)
0	($89,000)	($69,000)	($20,000)	($20,000)
1	$210,000	$66,000	$140,000	$130,000
2	$210,000	$65,000	$140,000	$110,000
3	$210,000	$64,000	$140,000	$100,000
4	$210,000	$64,000	$140,000	$91,000
5	$200,000	$62,000	$130,000	$76,000
6	$210,000	$63,000	$140,000	$72,000
7	$200,000	$62,000	$140,000	$64,000
8	$200,000	$62,000	$140,000	$58,000
9	$190,000	$61,000	$130,000	$48,000
10	$200,000	$62,000	$140,000	$46,000
11	$200,000	$62,000	$140,000	$41,000
12	$200,000	$62,000	$140,000	$37,000
13	$190,000	$60,000	$130,000	$30,000
14	$200,000	$62,000	$140,000	$29,000
15	$200,000	$62,000	$140,000	$26,000
16	$200,000	$62,000	$140,000	$23,000
17	$190,000	$60,000	$130,000	$19,000
18	$200,000	$60,000	$140,000	$18,000
19	$200,000	$60,000	$140,000	$16,000
20	$220,000	$75,000	$140,000	$15,000
			NPV@HR	$1,000,000

Notes: Numbers may be off due to rounding
Dollar values are in thousands
Negative values are denoted with parenthesis

In addition, Table 104 compares the number of major unit operations and utilities used by the two processes. As seen from this table, the fatty acid recovery design contains significantly more major unit operations than the mesophase pitch recovery design. This is due to the long distillation train required to separate and purify the fatty acids from the solvent. However, the mesophase pitch recovery design includes the pitching reactor unit operation, and processes tar which is a hot viscous material. This reactor is novel equipment and has never been built on a world scale, and tar is very hard to work with and leads to more operational and maintenance issues. For these reasons the fatty acid recovery design holds advantages over the mesophase pitch recovery design in the areas of maintainability, operability, and constructability.

The distillation train required for the separation of the fatty acids also results in larger demands for cooling water, boiler feed water, and natural gas. However, the addition of the pitching reactor to the mesophase pitch recovery design results in an increased boiler duty of 38,000 kW, but the additional production of fuel oil no. 5 in this section covers all additional duty requirements. The fatty acid recovery design also deals with acids and the solvent TMA which introduce environmental impact concerns. Environmental concerns are also found in the mesophase pitch recovery design when dealing with the hot, viscous tar. For these reasons, the mesophase pitch recovery design holds an advantage over the fatty acid design in the area of sustainability.

Table 104. Comparison of major unit operations and utility usage of mesophase pitch recovery and fatty acid recovery alternatives.

	Mesophase Pitch Recovery	**Fatty Acid Recovery**
Major Unit Operations	26	41
Cooling Water	550,000 m^3/yr	32.8 million m^3/yr
Boiler Feed Water	4.9 billion kg/yr	6.9 billion kg/yr
Natural Gas	N/A	11 million N m^3/yr
Total Boiler Duty	143,000 kW	105,000 kW

Both processes operate at roughly the same temperatures and pressures in all sections except for the heavy end processing and fatty acid recovery sections. The fatty acid recovery design requires the use of the solvent trimethylamine to remove the acids from the organic liquid product. Not only is this design dealing with large amounts of acids, this solvent is very flammable, and has potential health effects upon inhalation, skin contact, eye contact, and ingestion [58]. On the other had, the mesophase pitch recovery design deals with processing tars at very high temperatures. Therefore, the two designs have roughly the same amount of safety concerns, resulting in neither holding an advantage in the area of safety.

It is also possible to combine the two designs. This combination has the potential to significantly increase profit compared to either above. This would result in a larger NPV@12% over the 20 year life cycle ($2.5 billion ± 40%), but the addition of another section to the plant would also increase its complexity. As seen from the above comparison, this process is already more complex than the base design with mesophase pitch recovery. This increased complexity would result in even greater maintainability, operability, constructability, sustainability, and safety factors.

VI.B. Crop Oil Processing Integration

Previous undergraduate work performed at the University of North Dakota designed a world scale soybean oil processing plant. This design processed 7,500 MTPD of raw soybeans into 600,000 m^3/year of soybean oil [56]. The design used solvent extraction, with commercial hexane as the solvent, to remove the soybean oil from the beans. The solvent was then recovered from the oil and the meal through a setup similar to the Crown Iron Works recovery process [59]. This process uses a shallow bed extractor to remove the oil from the beans, and two-stage evaporation and stripping system to remove the hexane from the oil. A full description of the preliminary design and economic assessment surrounding the recovery of soybean oil from raw soybeans can be found in “Soybean Oil Extraction Using Commercial Hexane” [56].

In order to be in compliance with Minnesota regulations, over 99.9% of the solvent needs to be recovered from the oil, meal, and tramp air trapped within the system. To achieve this recovery, the soybean oil is sent through an oil stripper after it goes through two-stage evaporation. In addition, the oil was then sent through a degumming stage before it was sold. The degumming process removed phospholipids that are present in the oil, which are undesirable for food and biodiesel consumption.

The NCP-based biorefinery does not require a soybean oil with 99.9% of the solvent and phospholipids removed. Therefore, before the designs of the soybean oil processing plant were combined with the base design with mesophase pitch recovery biorefinery, these unneeded areas were removed. This resulted in removal of the equivalent of five major unit operations and their associated utilities.

The broad cost estimate for the design consisted of two large quotations for the two major sections of the plant. The first quote covered the soybean preparation and hull pelletizing sections, and the second quote covered the extraction, solvent recovery, MOS, and work tank sections of the plant. All equipment needed for the first quotation is required for the current design, but the second quotation contained the equipment that was removed. For this reason this price quotation was discounted by 10% to account for the removal of the oil stripper and associated degumming equipment.

The raw material required for the soybean oil processing plant is raw soybeans. The economic history of soybeans is shown in Figure 7. As can be seen from the figure, the price trend of soybeans closely follows the trend seen by soybean oil (Figure 1). Additionally, the major byproduct produced during soybean processing is soybean meal. This byproduct is a significant revenue source for soybean oil processing plants, and has the potential to effect the economics of an integrated biorefinery and oil processing plant. The economic history of soybean meal is shown in Figure 8.

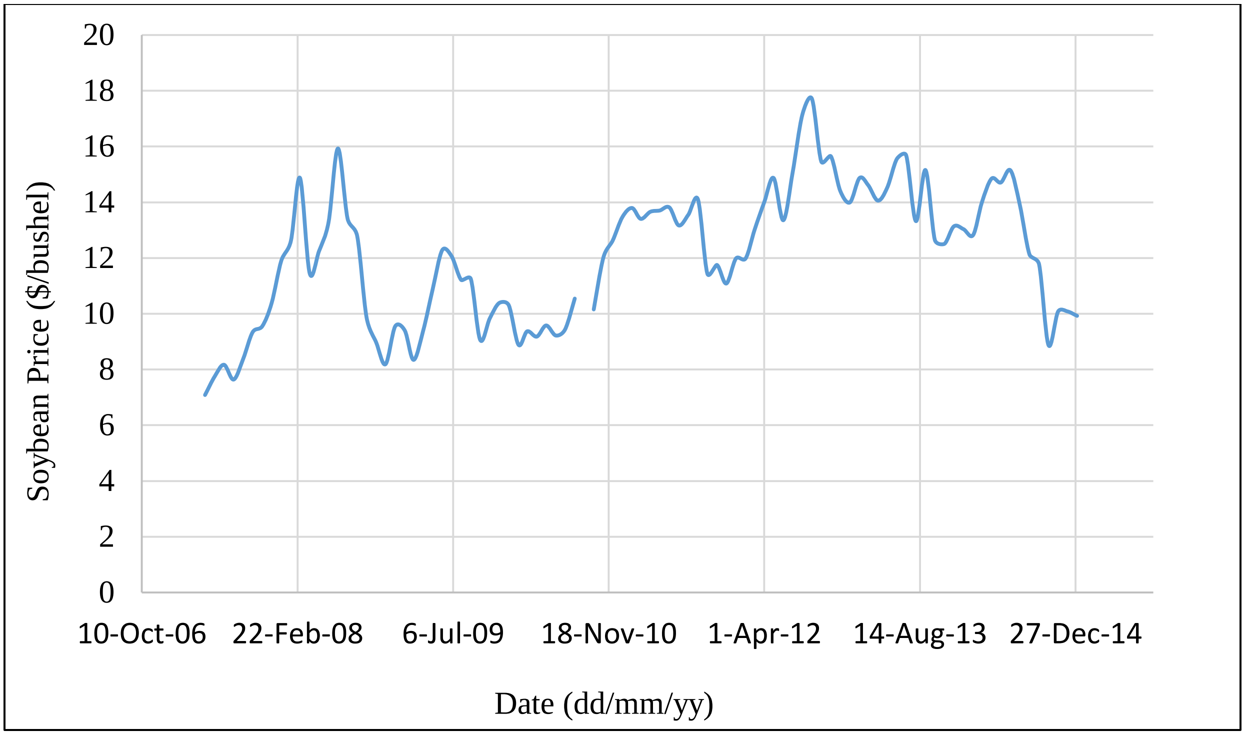


Figure 7. Soybean price trends [56].

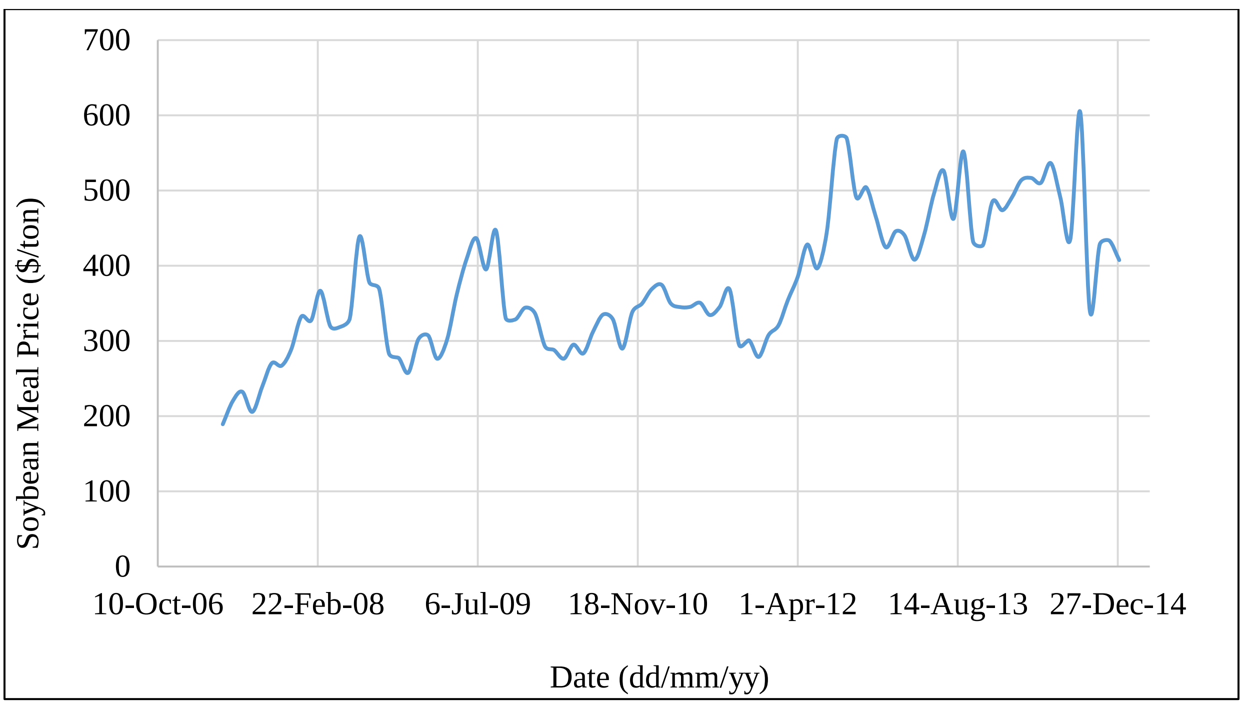


Figure 8. Soybean meal price trend data [56].

The following sections provide the economic analysis on an integrated soybean oil processing plant for each alternative developed in this work.

VI.B.1. Base Design Integrated with Soybean Processing Plant

VI.B.1.i. Broad Cost Estimate

The capital cost summary for the base design integrated with a soybean process plant is shown in Table 105. This table shows the total capital investment needed to complete the project, and was developed as described in Chapter II. The FCI was found to be $140 million, and the TCI was estimated to be $180 million ± 40%.

VI.B.1.ii. Raw Material and Manufacturing Cost Estimate

The raw material cost is based on purchasing raw soybeans off the open market for $0.33/kg [60]. The total raw material cost is $860 million per year.

The total manufacturing cost for the base design integrated with the soybean oil processing plant is $49 million per year, and $67 million per year on years the decarboxylate catalyst beds need to be replaced. The manufacturing cost includes chemicals and catalysts costs, operating labor costs, maintenance costs, and utility costs. Table 106 shows the overall yearly operating expense summary for the base design integrated with the soybean oil processing design. The plant has an operating factor of 95%. Intermediate results can be found in Appendix C, and communication records can be found in Appendix G.

The catalyst used for the decarboxylation reactors in the base design integrated with the soybean oil processing plant was a Ni catalyst. The initial charge for the catalyst (shown on the broad cost estimate) covers the total amount of catalyst needed (530,000 kg) for a price of $19 million. This amount is charged every four years in order to recharge the catalyst. It was assumed there was a 4% yearly depletion of the catalyst that needed to be replaced for the in between years. This results in a cost of $750,000 for those years. A quote from Johnson Matthey Catalysts was used for pricing ($28/m3).

The chemicals needed for the soybean oil processing plant include mineral oil and hexane. The initial charge for the chemical (shown on the broad cost estimate) covers the total amount of solvents needed for the soybean oil extraction process (260,000 kg hexane and 140 kg of mineral oil) for a total price of $99,000. It was assumed there was a 17% yearly depletion that needed to be replaced. This resulted in a yearly cost of $55,000. Prices for the solvents were taken from "Soybean Oil Extraction Using Commercial Hexane" [56].

The base design and integrated soybean oil processing consists of an equivalent of 51 major unit operations, which equates to 63 new operators to cover continuous operation, as described in Chapter II. An average operator salary of $62,800 was used, and taking into account an additional 15% for supervision, the yearly operating expense equates out to $4,600,000 per year [53]. The maintenance costs were found to be $8.3 million per year.

The utility costs is $35,000,000 per year. This value includes the boiler feed water, cooling water, electricity, refrigeration, process water, natural gas, and medium and high pressure steam. The steam was required for the soybean oil processing plant. The prices for all the utilities, except the electricity, were priced based off of Turton [54] heuristics. The electricity and natural gas values were found from typical ND and MN values [55].

VI.B.1.iii. Revenues

Revenue for the base design integrated with soybean oil processing comes from the sales of jet fuel, diesel fuel no. 2, petroleum naphtha, butane, acetic acid, vacuum bottoms, soybean meal, and pelleted hulls. Shipping costs were not considered when calculating the amount of revenues generated.

The transportation fuels, jet fuel, diesel fuel no. 2, and petroleum naphtha, produce a revenue of $140 million/year. This value was based on the production 120,000 liquid m3/year of petroleum naphtha that can be sold for $0.36/L, jet fuel at a rate of 170,000 liquid m3/year which is sold for $0.37/L, and diesel fuel no. 2 produced at 170,000 liquid m3/year and sold at $0.37/L. The remaining by products produce a revenue of $980 million/year. Of this $980 million, $930 million is from the sale of soybean meal. The total annual revenue for the base design integrated with the soybean oil processing plant is $1.1 billion/year.

VI.B.1.iv. Overall Profitability

The cash flow sheet for the base design and integrated soybean oil processing is shown in Table 107. The process has a NPV@12% of $770 million ± 40%. The project produces a gross income of $210 million per year, and has a DCFROR value of 60%. The positive NPV@12% value and a DCFROR value greater than 12% show that the investment is profitable over the project lifecycle.

VI.B.1.v. Break Even Point

Although a significant investment, with the current design and prices of products and raw materials the process recovers the initial investment within the second year of operation. In order for the process to break even over the 20 year lifecycle, the price of soybeans would have to rise to a price of \$0.40/kg (\$10.80/bushel). This last happened in 2013. The cash flow sheet based on a soybean price of \$0.40/kg can be seen in Table 108.

The saleable byproduct of soybean meal could potentially affect the profitability of the process. The price of meal would have to drop to \$0.40/kg (\$360/ton) for the process to break even, which last occurred in April, 2012. The cash flow sheet based on a soybean meal price of \$0.40/kg can be seen in Table 109.

Table 105. Broad cost estimate for base design with integrated soybean oil processing plant.

				Purchased Equipment Cost						
Equipment	**Equipment Description**	**Number**	**Capacity/Size Specs**	**Year 2004**	**Target Year (2016)**	**Material Factor, Fm**	**Pressure or other Factors, Fp**	**Base bare module factor, Fbm**	**Base bare module cost, Cbm**	**Total**
D-101	Flash 1	1	Height: 5.8 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$11,750	$16,000	2.5	1	7	$110,000	$110,000
D-102	Flash 2	1	Height: 5.3 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$11,500	$15,000	2.5	1	7	$110,000	$110,000
D-103	Flash 3	1	Height: 4.9 m Inside Diameter: 1.2m Vertical Orientation MOC: Carbon Steel	$11,000	$15,000	1	2	6	$89,000	$89,000
D-104	Flash 4	1	Height: 4.7 m Inside Diameter: 1.2 m Vertical Orientation MOC: Carbon Steel	$11,000	$15,000	1	1	4	$59,000	$59,000
D-105	Flash 5	1	Height: 5.4 m Inside Diameter: 1.4 m Vertical Orientation MOC: Carbon Steel	$10,000	$13,000	1	1	4	$54,000	$54,000
D-107	Acetic Flash 1	1	Length: 1.8 m Inside Diameter: 0.5 m Horizontal Orientation MOC: Stainless Steel Clad	$1,500	$2,000	2.5	1.5	8	$16,000	$16,000
D-108	Acetic Flash 2	1	Length: 3.4 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$5,000	$6,700	2.5	1	7	$47,000	$47,000

(continued)

Table 105. Broad cost estimate for base design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-109	Flash 7	1	Height: 2.7 m Inside Diameter: 0.7 m Vertical Orientation MOC: Carbon Steel	$3,000	$4,000	1	1	4	$16,000	$16,000
D-201	Atmospheric Column	1	Height: 8.4 m Diameter: 2.4 m Trays: 7 Feed: Tray 3 MOC: Stainless Steel Clad	$40,000	$54,000	2.5	1	7	$380,000	$380,000
D-201 Trays	Atmospheric Column Trays	7	Diameter: 2.4 m MOC: Stainless Steel	From Quote	$2,500	1	1	1.2	$3,000	$21,000
D-202	Vacuum Colum	1	Height: 20 m Diameter: 2.9 m Trays: 20 Feed: Tray 5 MOC: Stainless Steel Clad	70000	$94,000	2.5	1	7	$660,000	$660,000
D-202 Trays	Vacuum Column Trays	20	Diameter: 2.9 m MOC: Stainless Steel	From Quote	$2,800	1	1	1.2	$2,800	$56,000
D-204	Jet Diesel Cut	1	Height: 24 m Diameter: 2.6 m Trays: 25 Feed: Tray 13 MOC: Carbon Steel	50000	$67,000	1	1	4	$270,000	$270,000
D-204 Trays	Jet Diesel Cut Trays	25	Diameter: 2.6 m MOC: Stainless Steel	From Quote	$2,600	1	1.025	1.2	$3,200	$81,000
D-205	Naphtha-Jet Cut	1	Height: 27.5 m Diameter: 1.7 m Trays: 30 Feed: Tray 7 MOC: Carbon Steel	80000	$110,000	1	1	4	$430,000	$430,000

(continued)

Table 105. Broad cost estimate for base design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-205 Trays	Naphtha-Jet Cut Trays	30	Diameter: 1.7 m MOC: Stainless Steel	From Quote	$2,100	1	1	1.2	$2,500	$76,000
D-206	Diesel-Fuel Oil Cut	1	Height: 37 m Diameter: 2.8 m Trays: 40 Feed: Tray 28 MOC: Carbon Steel	150000	$200,000	1	1	4	$810,000	$810,000
D-206 Trays	Diesel-Fuel Oil Cut Trays	40	Diameter: 2.8 m MOC: Stainless Steel	From Quote	$2,800	1	1	1.2	$3,300	$130,000
D-207	Syngas Column	1	Height: 37 m Diameter: 2.7 m Trays: 40 Feed: Tray 5 MOC: Carbon Steel	125000	$170,000	1	3	8	$1,300,000	$1,300,000
D-207 Trays	Syngas Trays	40	Diameter: 2.7 m MOC: Stainless Steel	From Quote	$2,700	1	1	1.2	$3,300	$130,000
D-210	Debutanizer	1	Height: 11.5 m Diameter: 2.1 m Trays: 12 Feed: Tray 8 MOC: Carbon Steel	45000	$60,000	1	2	6	$360,000	$360,000
D-210 Trays	Debutanizer Trays	12	Diameter: 2.1 m MOC: Stainless Steel	From Quote	$2,300	1	1.18	1.2	$3,300	$40,000
D-301	Atmospheric Column Reflux Drum	1	Length: 3 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	4000	$5,400	2.5	1	4	$21,000	$21,000
D-302	Vacuum Column Reflux Drum	1	Length: 5.5 m Inside Diameter: 1.4 m Horizontal Orientation MOC: Stainless Steel Clad	$7,000	$9,400	2.5	1	4	$38,000	$38,000

(continued)

Table 105. Broad cost estimate for base design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-304	Jet-Diesel Cut Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	4000	$5,400	1	1	3	$16,000	$16,000
D-305	Naphtha-Jet Cut Reflux Drum	1	Length: 3 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	$4,000	$5,400	1	1	3	$16,000	$16,000
D-306	Diesel-Fuel Oil Cut Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	6000	$8,100	1	1	3	$24,000	$24,000
D-307	Syngas Column Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	$6,000	$8,100	1	1	3	$24,000	$24,000
D-308	Debutanizer Reflux Drum	1	Length: 3.7 m Inside Diameter: 0.9 m Horizontal Orientation MOC: Carbon Steel	5500	$7,400	1	1	3	$22,000	$22,000
D-310	Acetic Acid Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Stainless Steel Clad	$2,500	$3,400	2.5	1	4	$13,000	$13,000
D-311	Naphtha Drum	1	Length: 3.7 m Inside Diameter: 0.9 m Horizontal Orientation MOC: Carbon Steel	5500	$7,400	1	1	3	$22,000	$22,000
D-312	Flash 7 Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Stainless Steel Clad	$6,000	$8,100	2.5	1	4	$32,000	$32,000

(continued)

Table 105. Broad cost estimate for base design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-505 A/B	Stage 1 Light End Knockout Drum	2	Height: 3.6 m Inside Diameter: 1.2 m Horizontal Orientation MOC: Carbon Steel	10000	$13,000	1	1	4	$54,000	$110,000
D-506 A/B	Stage 2 Light End Knockout Drum	2	Height: 1.9 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Carbon Steel	$4,000	$5,400	1	1	4	$21,000	$43,000
D-507 A/B	Stage 3 Light End Knockout Drum	2	Height: 1.0 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Carbon Steel	2000	$2,700	1	1	4	$11,000	$21,000
E-101 A/B	Atmospheric Column Condenser	2	Surface Area: 660 m2 Heat Duty: 2500 kW MOC (shell/tube): cs/ss	$55,000	$74,000	1.7	1	4	$130,000	$250,000
E-102 A/B	Vacuum Column Condenser	2	Surface Area: 55 m2 Heat Duty: 5500 kW MOC (shell/tube): cs/ss	11000	$15,000	1.7	1	4	$59,000	$120,000
E-103 A/B	Jet Diesel Cut Condenser	2	Surface Area: 340 m2 Heat Duty: 2900 kW MOC (shell/tube): cs/ss	$32,000	$43,000	1.7	1	4	$170,000	$340,000
E-104 A/B	Syngas Condenser	2	Surface Area: 75 m2 Heat Duty: 580 kW MOC (shell/tube): cs/cs	12000	$16,000	1	1	3.2	$52,000	$100,000
E-105 A/B	Naphtha Jet Condenser	2	Surface Area: 500 m2 Heat Duty: 1600 kW MOC (shell/tube): cs/cs	$45,000	$60,000	1	1.1	3.2	$190,000	$390,000
E-106 A/B	Debutanizer Condenser	2	Surface Area: 44 m2 Heat Duty: 760 kW MOC (shell/tube): cs/cs	9500	$13,000	1	1	3.2	$41,000	$82,000

(continued)

Table 105. Broad cost estimate for base design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-107 A/B	Diesel-Fuel Oil Cut Condenser	2	Surface Area: 15 m2 Heat Duty: 2200 kW MOC (shell/tube): cs/cs	$4,000	$5,400	1	1	3.2	$17,000	$34,000
E-201 A/B	Cracking Cross Exchanger	2	Surface Area: 320 m2 Heat Duty: 14,000 kW MOC (shell/tube): cs/ss	30000	$40,000	1.7	1	4	$160,000	$320,000
E-202 A/B	Flash 2 Cooler	2	Surface Area: 170 m2 Heat Duty: 2700 kW MOC (shell/tube): cs/ss	$15,000	$20,000	1.7	1.25	4	$81,000	$160,000
E-204 A/B	Light End Cooler	2	Surface Area: 360 m2 Heat Duty: 1400 kW MOC (shell/tube): cs/cs	35000	$47,000	1	1.1	3.25	$150,000	$310,000
E-205 A/B	Debutanizer Cooler	2	Surface Area: 16 m2 Heat Duty: 340 kW MOC (shell/tube): cs/cs	$4,000	$5,400	1	1	3.2	$17,000	$34,000
E-207 A/B	Pre-Flash 5 Cooler	2	Surface Area: 41 m2 Heat Duty: 400 kW MOC (shell/tube): cs/ss	9500	$13,000	1.7	1	4	$51,000	$100,000
E-208 A/B	Post Diesel Decarbox Cooler	2	Surface Area: 33 m2 Heat Duty: 2800 kW MOC (shell/tube): cs/cs	$8,000	$11,000	1	1	3.2	$34,000	$69,000
E-209 A/B	Post Naphtha Decarbox Cooler	2	Surface Area: 74 m2 Heat Duty: 3600 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3.2	$43,000	$86,000
E-210 A/B	Interstage Cooler 1	2	Surface Area: 210 m2 Heat Duty: 750 kW MOC (shell/tube): cs/ss	$22,500	$30,000	1.7	1	4	$120,000	$240,000
E-211 A/B	Interstage Cooler 2	2	Surface Area: 130 m2 Heat Duty: 890 kW MOC (shell/tube): cs/ss	$14,000	$19,000	1.7	1	4	$75,000	$150,000
E-401 A/B	Atmospheric Column Reboiler	2	Surface Area: 200 m2 Heat Duty: 7300 kW MOC (shell/tube): ss clad/ss	$22,500	$30,000	3	1.1	6	$180,000	$360,000

(continued)

Table 105. Broad cost estimate for base design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-402 A/B	Vacuum Column Reboiler	2	Surface Area: 840 m2 Heat Duty: 4300 kW MOC (shell/tube): ss clad/ss	$60,000	$81,000	3	1.1	6	$480,000	$970,000
E-403 A/B	Naphtha Jet Cut Reboiler	2	Surface Area: 100 m2 Heat Duty: 2400 kW MOC (shell/tube): cs/ss	$12,000	$16,000	1.7	1	4	$64,000	$130,000
E-404 A/B	Jet Diesel Cut Reboiler	2	Surface Area: 170 m2 Heat Duty: 3500 kW MOC (shell/tube): cs/ss	$20,000	$27,000	1.7	1.1	4.5	$120,000	$240,000
E-405 A/B	Syngas Column Reboiler	2	Surface Area: 19 m2 Heat Duty: 1000 kW MOC (shell/tube): cs/ss	$8,000	$11,000	1.7	1.1	4.5	$48,000	$97,000
E-407 A/B	Debutanizer Reboiler	2	Surface Area: 11 m2 Heat Duty: 900 kW MOC (shell/tube): cs/ss	$4,000	$5,400	1.7	1.1	4.5	$24,000	$48,000
E-409 A/B	Diesel Fuel Oil Cut Reboiler	2	Surface Area: 200 m2 Heat Duty: 2200 kW MOC (shell/tube): cs/ss	$25,000	$34,000	1.7	1.1	4.5	$150,000	$300,000
E-502 A/B	TTCT Preheat	2	Surface Area: 460 m2 Heat Duty: 6300 kW MOC (shell/tube): ss clad /ss	$40,000	$54,000	3	1.25	7	$380,000	$750,000
E-503 A/B	Naphtha Decarbox Heater	2	Surface Area: 43 m2 Heat Duty: 3700 kW MOC (shell/tube): cs/ss	$10,000	$13,000	1.7	1.1	4.5	$60,000	$120,000
E-504 A/B	Diesel Decarbox Heater	2	Surface Area: 41 m2 Heat Duty: 1800 kW MOC (shell/tube): cs/ss	$10,000	$13,000	1.7	1.1	4.5	$60,000	$120,000
E-505 A/B	Pre Jet Diesel Cut Heat	2	Surface Area: 22 m2 Heat Duty: 540 kW MOC (shell/tube): cs/cs	$6,000	$8,100	1	1	3.2	$26,000	$52,000
E-1101 A/B	Jet Cooler	2	Surface Area: 260 m2 Heat Duty: 1200 kW MOC (shell/tube): cs/cs	$27,500	$37,000	1	1	3.2	$120,000	$240,000

(continued)

Table 105. Broad cost estimate for base design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-1102 A/B	Diesel Cooler	2	Surface Area: 130 m2 Heat Duty: 3000 kW MOC (shell/tube): cs/cs	$14,000	$19,000	1	1	3.2	$60,000	$120,000
E-1103 A/B	Fuel Oil Cooler 1	2	Surface Area: 6 m2 Heat Duty: 80 kW MOC (shell/tube): cs/cs	$3,000	$4,000	1	1	3.2	$13,000	$26,000
G-101 A/B	Flash 2 Compressor	2	Power: 17 kW Number of Stages: 1 MOC: Stainless Steel	From Quote	$18,000	1	1	2.52	$46,000	$91,000
G-103 A/B	Flash 5 Compressor	2	Power: 15 kW Number of Stages: 1 MOC: Carbon Steel	From Quote	$16,000	1	1	2.5	$41,000	$81,000
G-105	Light End Compressor	1	Power: 1900 kW Number of Stages: 3 MOC: Carbon Steel	From Quote	$2,000,000	1	1	2.5	$5,000,000	$5,000,000
L-101 A/B	PreCracking Pump	2	Power: 70 kW Suction Pressure: 110 kPa MOC: Stainless Steel	$12,500	$17,000	1.9	1	4.5	$76,000	$150,000
L-103 A/B	Pre Naphtha Decarbox	2	Power: 17 kW Suction Pressure: 120 kPa MOC: Stainless Steel	$10,000	$13,000	1.9	1	4.5	$60,000	$120,000
L-104 A/B	Atmospheric Reflux	2	Power: 1.6 kW Suction Pressure: 100 kPa MOC: Stainless Steel	$4,000	$5,400	1.9	1	3.2	$17,000	$34,000
L-105 A/B	Atmospheric Bottoms	2	Power: 810 W Suction Pressure: 110 kPa MOC: Stainless Steel	$3,900	$5,200	1.9	1	3.2	$17,000	$34,000
L-106 A/B	Vacuum Column Bottom	2	Power: 4.3 kW Suction Pressure: 33 kPa MOC: Stainless Steel	$5,000	$6,700	1.9	1	3.2	$21,000	$43,000
L-107 A/B	Vacuum Bottoms	2	Power: 760 W Suction Pressure: 100 kPa MOC: Stainless Steel	$3,800	$5,100	1.9	1	3.2	$16,000	$33,000

(continued)

Table 105. Broad cost estimate for base design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-108 A/B	Vacuum Reflux	2	Power: 5.1 kW Suction Pressure: 100 kPa MOC: Stainless Steel	$5,500	$7,400	1.9	1	3.2	$24,000	$47,000
L-109 A/B	PreDiesel Decarbox	2	Power: 29 kW Suction Pressure: 120 kPa MOC: Stainless Steel	$10,750	$14,000	1.9	1	4.5	$65,000	$130,000
L-110 A/B	PreJet-Diesel Cut Heat Pump	2	Power: 1.1 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$4,000	$5,400	1.4	1	3.2	$17,000	$34,000
L-111 A/B	Naphtha Product	2	Power: 200 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,200	$4,300	1.4	1	3.2	$14,000	$28,000
L-112 A/B	Jet Diesel Cut Reflux	2	Power: 4.4 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$5,250	$7,100	1.4	1	3.2	$23,000	$45,000
L-113 A/B	Jet Diesel Cut Bottoms	2	Power: 530 W Suction Pressure: 120 kPa MOC: Carbon Steel	$3,500	$4,700	1.4	1	3.2	$15,000	$30,000
L-114 A/B	Diesel Fuel Oil Cut Reflux	2	Power: 6.7 kW Suction Pressure: 100 kPa MOC: Stainless Steel	$8,500	$11,000	1.9	1	3.2	$37,000	$73,000
L-115 A/B	Diesel Fuel Oil Cut Bottoms	2	Power: 31 W Suction Pressure: 140 kPa MOC: Stainless Steel	$2,500	$3,400	1.9	1	3.2	$11,000	$21,000
L-116 A/B	Flash 5 Pump	2	Power: 48 W Suction Pressure: 100 kPa MOC: Stainless Steel	$2,750	$3,700	1.9	1	3.2	$12,000	$24,000
L-118 A/B	Jet Fuel Product	2	Power: 540 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,500	$4,700	1.4	1	3.2	$15,000	$30,000
L-119 A/B	Naphtha Jet Reflux	2	Power: 5.0 kW Suction Pressure: 110 kPa MOC: Carbon Steel	$5,250	$7,100	1.4	1	3.2	$23,000	$45,000

(continued)

Table 105. Broad cost estimate for base design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-120 A/B	Naphtha Jet Bottoms	2	Power: 510 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,250	$4,400	1.4	1	3.2	$14,000	$28,000
L-121 A/ B	Debutanizer reflux	2	Power: 1.7 kW Suction Pressure: 820 kPa MOC: Carbon Steel	$4,200	$5,600	1.4	1	3.2	$18,000	$36,000
L-127 A/B	Syngas Reflux	2	Power: 6 kW Suction Pressure: 2700 kPa MOC: Carbon Steel	$5,500	$7,400	1.4	1	3.2	$24,000	$47,000
L-128 A/B	Flash 7 Pump	2	Power: 250 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,300	$4,400	1.4	1	3.2	$14,000	$28,000
L-129 A/B	Diesel Product	2	Power: 330 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,400	$4,600	1.4	1	3.2	$15,000	$29,000
L-130 A/B	Vacuum Bottoms Product	2	Power: 400 W Suction Pressure: 42 kPa MOC: Stainless Steel	$3,400	$4,600	1.9	1	3.2	$15,000	$29,000
P-101	Refrigeration System	1	Load: 820-890 metric tons Power: 200 Volts	From Quote	$1,800,000	1	1	3.2	$5,900,000	$5,900,000
Q-101	TTCR Boiler	1	Duty: 65,000 kW	From Quote	$2,100,000	1	1	3.2	$6,700,000	$6,700,000
Q-102	High Pressure Steam Boiler	1	Duty: 78,000 kW	From Quote	$2,300,000	1	1	3.2	$7,400,000	$7,400,000
R-101	TTCR	1	Diameter: 6.1 m Length: 12.2 m Tubes: 10300 MOC: cs/inconel	From Quote	$30,000,000	0.7	1	3.2	$21,000,000	$21,000,000
R-102 A/B	Naphtha Decarboxylation Reactor	2	Diameter: 2.9 m Length: 17 m MOC: Stainless Steel Clad	From Quote	$840,000	1	1	3.2	$2,700,000	$5,400,000

(continued)

Table 105. Broad cost estimate for base design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
R-103 A/B	Diesel Decarboxylation Reactor	2	Diameter: 3.2 m Length: 19 m MOC: Stainless Steel Clad	From Quote	$1,000,000	1	1	3.2	$3,300,000	$6,700,000
	Extraction, Solvent Recovery, MOS, and Work Tank Sections	1	Capacity: 7500 MTPD	$17,850,000	$18,000,000	0.9	1	1	$16,000,000	$16,000,000
	Prep and Pelletizing Sections	1	Capacity: 7500 MTPD	$10,000,000	$9,900,000	1	1	1	$9,900,000	$9,900,000

Total Bare Module Cost	**CTBM**	$97,000,000
Contingency and Fees	**CTBM*0.18**	$17,000,000
Total Module Cost	**CTM**	$110,000,000
Auxiliary Facilities	**CTM*0.2**	$23,000,000
Fixed Capital Investment	**FCI**	$140,000,000
Working Capital	**FCI*0.15**	$21,000,000
Chemicals & Catalysts		$19,000,000
Total Capital Investment	**TCI**	$180,000,000

Notes: Actual numbers may be off due to rounding

Table 106. Operating expense summary for base design with integrated soybean oil processing plant.

Year	Chemicals and Catalysts	Operating Labor	Maintenance	Utilities	Yearly Total
1	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000
2	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000
3	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000
4	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000
5	$19,000,000	$4,600,000	$8,300,000	$35,000,000	$67,000,000
6	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000
7	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000
8	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000
9	$19,000,000	$4,600,000	$8,300,000	$35,000,000	$67,000,000
10	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000
11	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000
12	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000
13	$19,000,000	$4,600,000	$8,300,000	$35,000,000	$67,000,000
14	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000
15	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000
16	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000
17	$19,000,000	$4,600,000	$8,300,000	$35,000,000	$67,000,000
18	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000
19	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000
20	$850,000	$4,600,000	$8,300,000	$35,000,000	$49,000,000

Notes: Actual numbers may be off due to rounding

Table 107. Cash flow sheet for base design with integrated soybean oil processing plant.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR	Present Value @ DCFROR
-1	$-	$-	$-	$-	$-	$-	$-	($69,000)	($69,000)	($77,000)	($110,000)
0	$-	$-	$-	$-	$-	$-	$-	($110,000)	($110,000)	($110,000)	($110,000)
1	$1,100,000	$860,000	$49,000	$210,000	($21,000)	$190,000	($79,000)		$130,000	$120,000	$83,000
2	$1,100,000	$860,000	$49,000	$210,000	($18,000)	$190,000	($80,000)		$130,000	$100,000	$51,000
3	$1,100,000	$860,000	$49,000	$210,000	($16,000)	$200,000	($81,000)		$130,000	$93,000	$32,000
4	$1,100,000	$860,000	$49,000	$210,000	($14,000)	$200,000	($81,000)		$130,000	$82,000	$20,000
5	$1,100,000	$860,000	$67,000	$190,000	($13,000)	$180,000	($75,000)		$120,000	$67,000	$11,000
6	$1,100,000	$860,000	$49,000	$210,000	($11,000)	$200,000	($83,000)		$130,000	$65,000	$7,700
7	$1,100,000	$860,000	$49,000	$210,000	($9,800)	$200,000	($83,000)		$130,000	$58,000	$4,800
8	$1,100,000	$860,000	$49,000	$210,000	($8,700)	$200,000	($84,000)		$130,000	$51,000	$3,000
9	$1,100,000	$860,000	$67,000	$190,000	($7,600)	$190,000	($77,000)		$120,000	$42,000	$1,700
10	$1,100,000	$860,000	$49,000	$210,000	($7,200)	$200,000	($84,000)		$130,000	$41,000	$1,200
11	$1,100,000	$860,000	$49,000	$210,000	($7,200)	$200,000	($84,000)		$130,000	$36,000	$730
12	$1,100,000	$860,000	$49,000	$210,000	($7,200)	$200,000	($84,000)		$130,000	$33,000	$460
13	$1,100,000	$860,000	$67,000	$190,000	($7,200)	$190,000	($77,000)		$120,000	$27,000	$260
14	$1,100,000	$860,000	$49,000	$210,000	($7,200)	$200,000	($84,000)		$130,000	$26,000	$180
15	$1,100,000	$860,000	$49,000	$210,000	($7,200)	$200,000	($84,000)		$130,000	$23,000	$110
16	$1,100,000	$860,000	$49,000	$210,000	($7,200)	$200,000	($84,000)		$130,000	$21,000	$70
17	$1,100,000	$860,000	$67,000	$190,000	($7,200)	$190,000	($77,000)		$120,000	$17,000	$40
18	$1,100,000	$860,000	$49,000	$210,000		$210,000	($87,000)		$120,000	$16,000	$27
19	$1,100,000	$860,000	$49,000	$210,000		$210,000	($87,000)		$120,000	$14,000	$17
20	$1,100,000	$860,000	$49,000	$210,000		$210,000	($87,000)	$21,000	$140,000	$15,000	$12
Notes: Dollar values are in thousands									**NPV@HR**	$770,000	$0
Actual numbers may be off due to rounding									**DCFROR**	60%	
Numbers in parenthesis represent negative numbers									**HR**	12%	

Table 108. Cash flow sheet for base design with integrated soybean oil processing with a soybean price of $0.40/kg.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR
-1	$-	$-	$-	$-	$-	$-	$-	($69,000)	($69,000)	($77,000)
0	$-	$-	$-	$-	$-	$-	$-	($110,000)	($110,000)	($110,000)
1	$1,100,000	$1,000,000	$49,000	$36,000	($21,000)	$16,000	($6,400)		$30,000	$27,000
2	$1,100,000	$1,000,000	$49,000	$36,000	($18,000)	$18,000	($7,500)		$29,000	$23,000
3	$1,100,000	$1,000,000	$49,000	$36,000	($16,000)	$20,000	($8,400)		$28,000	$20,000
4	$1,100,000	$1,000,000	$49,000	$36,000	($14,000)	$22,000	($9,100)		$27,000	$17,000
5	$1,100,000	$1,000,000	$67,000	$18,000	($13,000)	$5,900	($2,400)		$16,000	$9,100
6	$1,100,000	$1,000,000	$49,000	$36,000	($11,000)	$25,000	($10,000)		$26,000	$13,000
7	$1,100,000	$1,000,000	$49,000	$36,000	($9,800)	$27,000	($11,000)		$25,000	$11,000
8	$1,100,000	$1,000,000	$49,000	$36,000	($8,700)	$28,000	($11,000)		$25,000	$10,000
9	$1,100,000	$1,000,000	$67,000	$18,000	($7,600)	$11,000	($4,500)		$14,000	$5,000
10	$1,100,000	$1,000,000	$49,000	$36,000	($7,200)	$29,000	($12,000)		$24,000	$7,800
11	$1,100,000	$1,000,000	$49,000	$36,000	($7,200)	$29,000	($12,000)		$24,000	$7,000
12	$1,100,000	$1,000,000	$49,000	$36,000	($7,200)	$29,000	($12,000)		$24,000	$6,200
13	$1,100,000	$1,000,000	$67,000	$18,000	($7,200)	$11,000	($4,700)		$14,000	$3,200
14	$1,100,000	$1,000,000	$49,000	$36,000	($7,200)	$29,000	($12,000)		$24,000	$5,000
15	$1,100,000	$1,000,000	$49,000	$36,000	($7,200)	$29,000	($12,000)		$24,000	$4,400
16	$1,100,000	$1,000,000	$49,000	$36,000	($7,200)	$29,000	($12,000)		$24,000	$4,000
17	$1,100,000	$1,000,000	$67,000	$18,000	($7,200)	$11,000	($4,700)		$14,000	$2,000
18	$1,100,000	$1,000,000	$49,000	$36,000		$36,000	($15,000)		$21,000	$2,800
19	$1,100,000	$1,000,000	$49,000	$36,000		$36,000	($15,000)		$21,000	$2,500
20	$1,100,000	$1,000,000	$49,000	$36,000		$36,000	($15,000)	$21,000	$42,000	$4,400
									NPV@HR	$0
									DCFROR	12%
									HR	12%

Notes: Dollar values are in thousands

Actual numbers may be off due to rounding

Numbers in parenthesis represent negative numbers

Table 109. Cash flow sheet for base design with integrated soybean oil processing with a soybean meal sale price of $0.40/kg.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR
-1	$-	$-	$-	$-	$-	$-	$-	($69,000)	($69,000)	($77,000)
0	$-	$-	$-	$-	$-	$-	$-	($110,000)	($110,000)	($110,000)
1	$950,000	$860,000	$49,000	$36,000	($21,000)	$16,000	($6,400)		$30,000	$27,000
2	$950,000	$860,000	$49,000	$36,000	($18,000)	$18,000	($7,500)		$29,000	$23,000
3	$950,000	$860,000	$49,000	$36,000	($16,000)	$20,000	($8,400)		$28,000	$20,000
4	$950,000	$860,000	$49,000	$36,000	($14,000)	$22,000	($9,100)		$27,000	$17,000
5	$950,000	$860,000	$67,000	$18,000	($13,000)	$5,900	($2,400)		$16,000	$9,100
6	$950,000	$860,000	$49,000	$36,000	($11,000)	$25,000	($10,000)		$26,000	$13,000
7	$950,000	$860,000	$49,000	$36,000	($9,800)	$27,000	($11,000)		$25,000	$11,000
8	$950,000	$860,000	$49,000	$36,000	($8,700)	$28,000	($11,000)		$25,000	$10,000
9	$950,000	$860,000	$67,000	$18,000	($7,600)	$11,000	($4,500)		$14,000	$5,000
10	$950,000	$860,000	$49,000	$36,000	($7,200)	$29,000	($12,000)		$24,000	$7,800
11	$950,000	$860,000	$49,000	$36,000	($7,200)	$29,000	($12,000)		$24,000	$7,000
12	$950,000	$860,000	$49,000	$36,000	($7,200)	$29,000	($12,000)		$24,000	$6,200
13	$950,000	$860,000	$67,000	$18,000	($7,200)	$11,000	($4,700)		$14,000	$3,200
14	$950,000	$860,000	$49,000	$36,000	($7,200)	$29,000	($12,000)		$24,000	$5,000
15	$950,000	$860,000	$49,000	$36,000	($7,200)	$29,000	($12,000)		$24,000	$4,400
16	$950,000	$860,000	$49,000	$36,000	($7,200)	$29,000	($12,000)		$24,000	$4,000
17	$950,000	$860,000	$67,000	$18,000	($7,200)	$11,000	($4,700)		$14,000	$2,000
18	$950,000	$860,000	$49,000	$36,000		$36,000	($15,000)		$21,000	$2,800
19	$950,000	$860,000	$49,000	$36,000		$36,000	($15,000)		$21,000	$2,500
20	$950,000	$860,000	$49,000	$36,000		$36,000	($15,000)	$21,000	$42,000	$4,400
									NPV@HR	$0
									DCFROR	12%
									HR	12%

Notes: Dollar values are in thousands

Actual numbers may be off due to rounding

Numbers in parenthesis represent negative numbers

VI.B.2. Fatty Acid Recovery Design with Integrated Soybean Plant

VI.B.2.i. Broad Cost Estimate

The capital cost summary for the fatty acid recovery design integrated with a soybean process plant is shown in Table 110. This table shows the total capital investment needed to complete the project, and was developed as described in Chapter II. The FCI was found to be $140 million, and the TCI was estimated to be $160 million ± 40%.

VI.B.2.ii. Raw Material and Manufacturing Cost Estimate

The raw material cost is based on purchasing raw soybeans off the open market for $0.33/kg [60]. The total raw material cost is $860 million per year.

The total manufacturing cost for the fatty acid recovery design integrated with the soybean oil processing plant is $48 million per year, and $50 million per year on years the decarboxylate catalyst beds need to be replaced. The manufacturing cost includes chemicals and catalysts costs, operating labor costs, maintenance costs, and utility costs. Table 111 shows the overall yearly operating expense summary for the fatty acid recovery design integrated with the soybean oil processing design. The plant has an operating factor of 95%. Intermediate results can be found in Appendix C, and communication records can be found in Appendix G.

The catalyst used for the decarboxylation reactors in the fatty acid recovery design integrated with the soybean oil processing plant was a Ni catalyst. The initial charge for the catalyst (shown on the broad cost estimate) covers the total amount of catalyst needed (62 m^3) for a price of $2.2 million. This amount is charged every four years in order to recharge the catalyst. It was assumed there was a 4% yearly depletion of the catalyst that needed to be replaced for the in between years. This results in a cost of $86,000 for those years. A quote from Johnson Matthey Catalysts was used for pricing ($28/m3).

The chemical required for the fatty acid recovery biorefinery needed for the extraction of the fatty acids from the crackate is 25 wt% trimethylamine (TMA). The initial charge for the chemical (shown on the broad cost estimate) covers the total amount of solvent needed for the extraction process (14,000 kg) for a price of $500,000. It was assumed there was a 17% yearly depletion that needed to be replaced. This resulted in a yearly cost of $86,000. A quote from Penta International Corporation was used for pricing ($7.50/kg).

The chemicals needed for the soybean oil processing plant include mineral oil and hexane. The initial charge for the chemical (shown on the broad cost estimate) covers the total amount of solvents needed for the soybean oil extraction process (260,000 kg hexane and 140 kg of mineral oil) for a total price of $99,000. It was assumed there was a 17% yearly depletion that needed to be replaced. This resulted in a yearly cost of $55,000. Prices for the solvents were taken from “Soybean Oil Extraction Using Commercial Hexane” [56].

The fatty acid recovery design and integrated soybean oil processing consists of an equivalent of 68 major unit operations, which equates to 82 new operators to cover continuous operation, as described in Chapter II. An average operator salary of $62,800 was used, and taking into account an additional 15% for supervision, the yearly operating expense equates out to $5,900,000 per year [53]. The maintenance costs were found to be $8.3 million per year.

The utility costs is $33,000,000 per year. This value includes the boiler feed water, cooling water, electricity, refrigeration, process water, natural gas, and medium and high pressure steam. The steam was required for the soybean oil processing plant. The prices for all the utilities, except the electricity, were priced based off of Turton [54] heuristics. The electricity and natural gas values were found from typical ND and MN values [55].

VI.B.2.iii. Revenues

Revenue for the fatty acid recovery design and integrated soybean oil processing comes from the sales of jet fuel, diesel fuel no. 2, petroleum naphtha, butane, vacuum bottoms, and C2-C11 fatty acids, soybean meal, and pelleted hulls. Shipping costs were not considered when calculating the amount of revenues generated.

The transportation fuels, jet fuel, diesel fuel no. 2, and petroleum naphtha, produce a revenue of $160 million/year. This value was based on the production of 79,000 liquid m3/year of petroleum naphtha that can be sold for $0.36/L, jet fuel at a rate of $190,000 liquid m3/year which is sold for $0.37/L, and diesel fuel no. 2 produced at 260,000 liquid m3/year and sold at $0.37/L. The remaining by products produce a revenue of $1.2 billion/year. Of this $1.2 billion, $930 million is from the sale of soybean meal. The total annual revenue for the fatty acid recovery design integrated with the soybean oil processing plant is $1.4 billion/year.

VI.B.2.iv. Overall Profitability

The cash flow sheet for the fatty acid recovery design and integrated soybean oil processing is shown in Table 112. The process has a NPV@12% of $1.9 billion ± 40%. The project produces a gross income of $470 million per year, and has a DCFROR value of 120%. The positive NPV@12% value and a DCFROR value greater than 12% show that the investment is profitable over the project lifecycle.

VI.B.2.v. Break Even Point

Although a significant investment, with the current design and prices of products and raw materials the process recovers the initial investment in the first year of operation. In order for the process to break even over the 20 year lifecycle, the price of soybeans would have to rise to a price of $0.50/kg ($13.80/bushel). This last happened in August, 2013. The cash flow sheet based on a soybean price of $0.50/kg can be seen in Table 113.

The saleable byproduct of soybean meal could potentially affect the profitability of the process. The price of meal would have to drop to $0.26/kg ($240/ton) for the process to break even, which last occurred in 2008. The cash flow sheet based on a soybean meal price of $0.26/kg can be seen in Table 114.

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant.

				Purchased Equipment Cost						
Equipment	**Equipment Description**	**Number**	**Capacity/Size Specs**	**Basis Date Year 2004**	**Target Year (2016)**	**Material Factor, Fm**	**Pressure or other Factors, Fp**	**Base bare module factor, Fbm**	**Base bare module cost, Cbm**	**Total**
D-601	Flash 1	1	Height: 5.8 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$17,500	$24,000	2.5	1	7	$160,000	$160,000
D-602	Flash 2	1	Height: 5.8 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$17,500	$24,000	2.5	1	7	$160,000	$160,000
D-603	Flash 3	1	Height: 2 m Inside Diameter: 1.2 m Vertical Orientation MOC: Carbon Steel	$6,500	$8,700	1	2	6	$52,000	$52,000
D-604	Acetic Acid Separator 1	1	Height: 1.8 m Inside Diameter: 0.5 m Vertical Orientation MOC: Stainless Steel Clad	$3,500	$4,700	2.5	1.5	7	$33,000	$33,000
D-605	Acetic Acid Separator 2	1	Height: 3.4 m Inside Diameter: 0.8 m Vertical Orientation MOC: Stainless Steel Clad	$10,000	$13,000	2.5	1	4	$54,000	$54,000
D-606	Flash 4	1	Height: 2.8 m Inside Diameter: 0.8 m Vertical Orientation MOC: Carbon Steel	$9,000	$12,000	1	1	4	$48,000	$48,000
D-607	Flash 5	1	Height: 2.8 m Inside Diameter: 0.8 m Vertical Orientation MOC: Carbon Steel	$9,000	$12,000	1	1.5	5	$60,000	$60,000
D-701	Atmospheric Column	1	Height: 8.2 m Diameter: 2.1 m Trays: 7 Feed: Tray 5 MOC: Carbon Steel	$30,000	$40,000	1	1	4	$160,000	$160,000

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-701 Trays	Atmospheric Column Trays	7	Diameter: 2.1 m MOC: Stainless Steel	From Quote	$2,300	1	1	1.2	$2,800	$20,000
D-702	Vacuum Column	1	Height: 21.8 m Diameter: 4.4 m Trays: 20 Feed: Tray 10 MOC: Carbon Steel	$125,000	$170,000	1	1	4	$670,000	$670,000
D-702 Trays	Vacuum Column Trays	20	Diameter: 4.4 m MOC: Stainless Steel	From Quote	$3,600	1	1	1.2	$4,300	$86,000
D-703	Water Removal Column	1	Height: 18.8 m Diameter: 2.2 m Trays: 19 Feed: Tray 12 MOC: Stainless Steel Clad	$65,000	$87,000	2.5	1	7	$610,000	$610,000
D-703 Trays	Water Removal Column Trays	19	Diameter: 2.2 m MOC: Stainless Steel	From Quote	$2,400	1	1	1.2	$2,900	$54,000
D-704	C2-C4 Split Column	1	Height: 19 m Diameter: 1.6 m Trays: 20 Feed: Tray 16 MOC: Stainless Steel Clad	$50,000	$67,000	2.5	1	7	$470,000	$470,000
D-704 Trays	C2-C4 Split Column Trays	20	Diameter: 1.6 m MOC: Stainless Steel	From Quote	$1,900	1	1	1.2	$2,300	$46,000
D-705	Acetic Acid Column	1	Height: 20.7 m Diameter: 1.5 m Trays: 22 Feed: Tray 12 MOC: Stainless Steel Clad	$50,000	$67,000	2.5	1	7	$470,000	$470,000
D-705 Trays	Acetic Acid Column Trays	22	Diameter: 1.5 m MOC: Stainless Steel	From Quote	$1,900	1	1	1.2	$2,300	$50,000
D-706	C6-C7 Split Column	1	Height: 31.5 m Diameter: 1.1 m Trays: 35 Feed: Tray 15 MOC: Stainless Steel Clad	$70,000	$94,000	2.5	1	7	$660,000	$660,000

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-706 Trays	C6-C7 Split Column Trays	35	Diameter: 1.1 m MOC: Stainless Steel	From Quote	$1,500	1	1	1.2	$1,800	$65,000
D-707	C4-C5 Split Column	1	Height: 28.3 m Diameter: 0.4 m Trays: 32 Feed: Tray 12 MOC: Stainless Steel Clad	$70,000	$94,000	2.5	1	7	$660,000	$660,000
D-707 Trays	C4-C5 Split Column Trays	32	Diameter: 0.4 m MOC: Stainless Steel	From Quote	$930	1	1	1.2	$1,100	$36,000
D-708	C3-C4 Product Column	1	Height: 24.7 m Diameter: 0.3 m Trays: 28 Feed: Tray 15 MOC: Stainless Steel Clad	$35,000	$47,000	2.5	1	7	$330,000	$330,000
D-708 Trays	C3-C4 Product Column Trays	28	Diameter: 0.3 m MOC: Stainless Steel	From Quote	$730	1	1	1.2	$870	$24,000
D-709	C5-C6 Product Column	1	Height: 26.7 m Diameter: 0.6 m Trays: 30 Feed: Tray 15 MOC: Stainless Steel Clad	$35,000	$47,000	2.5	1	7	$330,000	$330,000
D-709 Trays	C5-C6 Product Column Trays	30	Diameter: 0.6 m MOC: Stainless Steel	From Quote	$1,100	1	1	1.2	$1,300	$40,000
D-710	C8-C9 Split Column	1	Height: 24.7 m Diameter: 2.1 m Trays: 26 Feed: Tray 15 MOC: Stainless Steel Clad	$80,000	$110,000	2.5	1	7	$750,000	$750,000
D-710 Trays	C8-C9 Split Column Trays	26	Diameter: 2.1 m MOC: Stainless Steel	From Quote	$2,300	1	1	1.2	$2,800	$72,000
D-711	C7-C8 Product Column	1	Height: 25.7 m Diameter: 1.3 m Trays: 28 Feed: Tray 15 MOC: Stainless Steel Clad	$60,000	$81,000	2.5	1	7	$560,000	$560,000

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-711 Trays	C7-C8 Product Column Trays	28	Diameter: 1.3 m MOC: Stainless Steel	From Quote	$1,700	1	1	1.2	$2,100	$57,000
D-712	C10-C11 Split Column	1	Height: 30.3 m Diameter: 2.4 m Trays: 32 Feed: Tray 19 MOC: Stainless Steel Clad	$150,000	$200,000	2.5	1	7	$1,400,000	$1,400,000
D-712 Trays	C10-C11 Split Column Trays	32	Diameter: 2.4 m MOC: Stainless Steel	From Quote	$2,500	1	1	1.2	$3,000	$96,000
D-713	C9-C10 Product Column	1	Height: 29.4 m Diameter: 1.5 m Trays: 32 Feed: Tray 17 MOC: Stainless Steel Clad	$90,000	$120,000	2.5	1	7	$850,000	$850,000
D-713 Trays	C9-C10 Product Column Trays	32	Diameter: 1.5 m MOC: Stainless Steel	From Quote	$1,900	1	1	1.2	$2,300	$72,000
D-714	C11 Product Column	1	Height: 27.8 m Diameter: 1.7 m Trays: 30 Feed: Tray 17 MOC: Stainless Steel Clad	$85,000	$110,000	2.5	1	7	$800,000	$800,000
D-714 Trays	C11 Product Column Trays	30	Diameter: 1.7 m MOC: Stainless Steel	From Quote	$2,000	1	1	1.2	$2,400	$73,000
D-715	Hexane Splitter Column	1	Height: 7.9 m Diameter: 0.9 m Trays: 8 Feed: Tray 4 MOC: Carbon Steel	$20,000	$27,000	1	1	4	$110,000	$110,000
D-715 Trays	Hexane Splitter Column Trays	8	Diameter: 0.9 m MOC: Stainless Steel	From Quote	$1,000	1	1	1.2	$1,200	$9,900
D-716	Naphtha Jet Cut Column	1	Height: 27.7 m Diameter: 1.6 m Trays: 30 Feed: Tray 7 MOC: Carbon Steel	$100,000	$130,000	1	1	4	$540,000	$540,000

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-716 Trays	Naphtha Jet Cut Column Trays	30	Diameter: 1.6 m MOC: Stainless Steel	From Quote	$2,000	1	1	1.2	$2,400	$71,000
D-717	Jet Diesel Cut Column	1	Height: 24.8 m Diameter: 3.0 m Trays: 25 Feed: Tray 13 MOC: Carbon Steel	$125,000	$170,000	1	1	4	$670,000	$670,000
D-717 Trays	Jet Diesel Cut Column Trays	25	Diameter: 3.0 m MOC: Stainless Steel	From Quote	$2,900	1	1	1.2	$3,400	$86,000
D-718	Diesel Fuel Oil Cut Column	1	Height: 47.9 m Diameter: 4.3 m Trays: 50 Feed: Tray 23 MOC: Carbon Steel	$250,000	$340,000	1	1	4	$1,300,000	$1,300,000
D-718 Trays	Diesel Fuel Oil Cut Column Trays	50	Diameter: 4.3 m MOC: Stainless Steel	From Quote	$3,600	1	1	1.2	$4,300	$210,000
D-719	Syngas Column	1	Height: 37.1 m Diameter: 0.2 m Trays: 40 Feed: Tray 15 MOC: Carbon Steel	$30,000	$40,000	1	3	8	$320,000	$320,000
D-719 Trays	Syngas Column Trays	40	Diameter: 0.2 m MOC: Stainless Steel	From Quote	$500	1	3	1.2	$1,800	$73,000
D-720	Debutanizer Column	1	Height: 11.2 m Diameter: 0.9 m Trays: 12 Feed: Tray 8 MOC: Carbon Steel	$25,000	$34,000	1	1.5	5	$170,000	$170,000
D-720 Trays	Debutanizer Column Trays	12	Diameter: 0.9 m MOC: Stainless Steel	From Quote	$1,400	1	2	1.2	$3,300	$39,000

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-801	Atmospheric Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	$2,500	$3,400	1	1	3	$10,000	$10,000
D-802	Vacuum Column Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	$6,000	$8,100	1	1	3	$24,000	$24,000
D-803	Water Removal Column Reflux Drum	1	Length: 5.5 m Inside Diameter: 1.4 m Horizontal Orientation MOC: Stainless Steel Clad	$10,000	$13,000	2.5	1	4	$54,000	$54,000
D-804	C2-C4 Split Column Reflux Drum	1	Length: 2.4 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Stainless Steel Clad	$2,000	$2,700	2.5	1	4	$11,000	$11,000
D-805	Acetic Acid Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$2,500	$3,400	2.5	1	4	$13,000	$13,000
D-806	C6-C7 Split Column Reflux Drum	1	Length: 2.4 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Stainless Steel Clad	$2,000	$2,700	2.5	1	4	$11,000	$11,000
D-807	C4-C5 Split Column Reflux Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Stainless Steel Clad	$1,000	$1,300	2.5	1	4	$5,400	$5,400
D-808	C3-C4 Product Column Reflux Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Stainless Steel Clad	$1,000	$1,300	2.5	1	4	$5,400	$5,400

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-809	C5-C6 Product Column Reflux Drum	1	Length: 1.8 m Inside Diameter: 0.5 m Horizontal Orientation MOC: Stainless Steel Clad	$1,500	$2,000	2.5	1	4	$8,100	$8,100
D-810	C8-C9 Split Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$2,500	$3,400	2.5	1	4	$13,000	$13,000
D-811	C7-C8 Product Column Reflux Drum	1	Length: 2.4 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Stainless Steel Clad	$2,000	$2,700	2.5	1	4	$11,000	$11,000
D-812	C10-C11 Split Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$2,500	$3,400	2.5	1	4	$13,000	$13,000
D-813	C9-C10 Product Column Reflux Drum	1	Length: 2.4 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Stainless Steel Clad	$2,000	$2,700	2.5	1	4	$11,000	$11,000
D-814	C11 Product Column Reflux Drum	1	Length: 2.4 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Stainless Steel Clad	$2,000	$2,700	2.5	1	4	$11,000	$11,000
D-815	Hexane Splitter Column Reflux Drum	1	Length: 1.8 m Inside Diameter: 0.5 m Horizontal Orientation MOC: Carbon Steel	$1,500	$2,000	1	1	3	$6,000	$6,000
D-816	Naphtha Jet Cut Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	$2,500	$3,400	1	1	3	$10,000	$10,000

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-817	Jet Diesel Cut Column Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	$6,000	$8,100	1	1	3	$24,000	$24,000
D-818	Diesel Fuel Oil Cut Column Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	$6,000	$8,100	1	1	3	$24,000	$24,000
D-819	Syngas Column Reflux Drum	1	Length: 3.6 m Inside Diameter: 0.9 m Horizontal Orientation MOC: Carbon Steel	$4,000	$5,400	1	3	6	$32,000	$32,000
D-820	Debutanizer Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	$2,500	$3,400	1	1.5	4	$13,000	$13,000
D-821	Acetic Acid Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Stainless Steel Clad	$2,500	$3,400	2.5	1	4	$13,000	$13,000
D-822	Naphtha Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Carbon Steel	$2,500	$3,400	1	1.5	4	$13,000	$13,000
D-901	Fatty Acid Extractor	2	Height: 6.6 m Diameter: 2.2 m Residence Time: 15 min MOC: Stainless Steel Clad	$25,000	$34,000	2.5	1	7	$240,000	$470,000
D-902	Fatty Acid Separator	1	Height: 5.3 m Diameter: 1.4 m MOC: Stainless Steel Clad	$17,500	$24,000	2.5	1	7	$160,000	$160,000

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-1001 A/B	Flash 3 Compressor Knockout Drum	2	Height: 0.1 m Inside Diameter: 0.02 m Horizontal Orientation MOC: Carbon Steel	$1,000	$1,300	1	1	3	$4,000	$8,100
D-1002 A/B	Stage 1 Light End Knock out Drum	2	Height: 3.1 m Inside Diameter: 1.0 m Horizontal Orientation MOC: Carbon Steel	$5,000	$6,700	1	1	3	$20,000	$40,000
D-1003 A/B	Stage 2 Light End Knock out Drum	2	Height: 1.7 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Carbon Steel	$1,750	$2,400	1	1.5	4	$9,400	$19,000
D-1004 A/B	Stage 3 Light End Knock out Drum	2	Height: 0.9 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Carbon Steel	$1,000	$1,300	1	3	6	$8,100	$16,000
E-601 A/B	Atmospheric Column Condenser	2	Surface Area: 930 m2 Heat Duty: 1950 kW MOC (shell/tube): cs/cs	$40,000	$54,000	1	1	3	$160,000	$320,000
E-602 A/B	Vacuum Column Condenser	2	Surface Area: 51 m2 Heat Duty: 3100 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3	$40,000	$81,000
E-603 A/B	Hexane Splitter Condenser	2	Surface Area: 100 m2 Heat Duty: 97 kW MOC (shell/tube): cs/cs	$15,000	$20,000	1	1	3	$60,000	$120,000
E-604 A/B	Naphtha Jet Cut Column Condenser	2	Surface Area: 46 m2 Heat Duty: 825 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3	$40,000	$81,000
E-605 A/B	Jet Diesel Cut Column Condenser	2	Surface Area: 52 m2 Heat Duty: 2100 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3	$40,000	$81,000
E-606 A/B	Diesel Fuel Oil Column Condenser	2	Surface Area: 12 m2 Heat Duty: 1770 kW MOC (shell/tube): cs/cs	$5,000	$6,700	1	1	3	$20,000	$40,000

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-607 A/B	Syngas Column Condenser	2	Surface Area: 230 m2 Heat Duty: 390 kW MOC (shell/tube): cs/cs	$25,000	$34,000	1	1.1	3.5	$120,000	$240,000
E-608 A/B	Debutanizer Column Condenser	2	Surface Area: 99 m2 Heat Duty: 830 kW MOC (shell/tube): cs/cs	$15,000	$20,000	1	1.1	3.5	$71,000	$140,000
E-609 A/B	Water Removal Column Condenser	2	Surface Area: 4540 m2 Heat Duty: 53800 kW MOC (shell/tube): cs/ss	$150,000	$200,000	1.7	1	4	$810,000	$1,600,000
E-610 A/B	C2-C4 Split Column Condenser	2	Surface Area: 1380 m2 Heat Duty: 5500 kW MOC (shell/tube): cs/ss	$70,000	$94,000	1.7	1	4	$380,000	$750,000
E-611 A/B	Acetic Acid Column Condenser	2	Surface Area: 290 m2 Heat Duty: 3400 kW MOC (shell/tube): cs/ss	$30,000	$40,000	1.7	1	4	$160,000	$320,000
E-612 A/B	C6-C7 Condenser	2	Surface Area: 18 m2 Heat Duty: 600 kW MOC (shell/tube): cs/ss	$6,000	$8,100	1.7	1	4	$32,000	$64,000
E-613 A/B	C4-C5 Condenser	2	Surface Area: 3 m2 Heat Duty: 50 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000
E-614 A/B	C3-C4 Condenser	2	Surface Area: 3 m2 Heat Duty: 71 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000
E-615 A/B	C5-C6 Condenser	2	Surface Area: 9 m2 Heat Duty: 270 kW MOC (shell/tube): cs/ss	$5,000	$6,700	1.7	1	4	$27,000	$54,000
E-616 A/B	C8-C9 Condenser	2	Surface Area: 43 m2 Heat Duty: 1630 kW MOC (shell/tube): cs/ss	$10,000	$13,000	1.7	1	4	$54,000	$110,000
E-617 A/B	C7-C8 Condenser	2	Surface Area: 22 m2 Heat Duty: 760 kW MOC (shell/tube): cs/ss	$6,500	$8,700	1.7	1	4	$35,000	$70,000

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Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-618 A/B	C10-C11 Condenser	2	Surface Area: 1 m2 Heat Duty: 66 kW MOC (shell/tube): cs/ss	$2,000	$2,700	1.7	1	4	$11,000	$21,000
E-619 A/B	C9-C10 Condenser	2	Surface Area: 33 m2 Heat Duty: 650 kW MOC (shell/tube): cs/ss	$7,000	$9,400	1.7	1	4	$38,000	$75,000
E-620 A/B	C11 Condenser	2	Surface Area: 18 m2 Heat Duty: 430 kW MOC (shell/tube): cs/ss	$6,500	$8,700	1.7	1	4	$35,000	$70,000
E-701 A/B	Post Cracking Cooler	2	Surface Area: 320 m2 Heat Duty: 14400 kW MOC (shell/tube): cs/ss	$30,000	$40,000	1.7	1.1	4.25	$170,000	$340,000
E-702 A/B	Flash 2 Cooler	2	Surface Area: 170 m2 Heat Duty: 2700 kW MOC (shell/tube): cs/ss	$20,000	$27,000	1.7	1	4	$110,000	$210,000
E-703 A/B	Pre Flash 3 Cooler	2	Surface Area: 60 m2 Heat Duty: 250 kW MOC (shell/tube): cs/cs	$10,250	$14,000	1	1	3	$41,000	$83,000
E-704 A/B	Syngas Cooler	2	Surface Area: 810 m2 Heat Duty: 2400 kW MOC (shell/tube): cs/cs	$60,000	$81,000	1	1.1	3.5	$280,000	$560,000
E-705 A/B	Stage 1 Cooler	2	Surface Area: 37 m2 Heat Duty: 530 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3	$40,000	$81,000
E-706 A/B	Stage 2 Cooler	2	Surface Area: 40 m2 Heat Duty: 640 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1.1	3.5	$47,000	$94,000
E-707 A/B	Debutanizer Cooler	2	Surface Area: 12 m2 Heat Duty: 250 kW MOC (shell/tube): cs/cs	$6,000	$8,100	1	1.1	3.5	$28,000	$56,000
E-708 A/B	C6-C7 Cooler	2	Surface Area: 3 m2 Heat Duty: 58 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-709 A/B	C4-C5 Cooler	2	Surface Area: 3 m2 Heat Duty: 50 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000
E-710 A/B	C8-C9 Cooler	2	Surface Area: 7 m2 Heat Duty: 390 kW MOC (shell/tube): cs/ss	$5,000	$6,700	1.7	1	4	$27,000	$54,000
E-711 A/B	C10-C11 Cooler	2	Surface Area: 1 m2 Heat Duty: 66 kW MOC (shell/tube): cs/ss	$2,000	$2,700	1.7	1	4	$11,000	$21,000
E-712 A/B	C11 Cooler	2	Surface Area: 3 m2 Heat Duty: 200 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000
E-713 A/B	Flash 4 Cooler	2	Surface Area: 7 m2 Heat Duty: 560 kW MOC (shell/tube): cs/cs	$5,000	$6,700	1	1	3	$20,000	$40,000
E-714 A/B	Pre Jet Diesel Cut Cooler	2	Surface Area: 3 m2 Heat Duty: 130 kW MOC (shell/tube): cs/cs	$3,000	$4,000	1	1	3	$12,000	$24,000
E-801 A/B	TTCR Preheat	2	Surface Area: 290 m2 Heat Duty: 6300 kW MOC (shell/tube): ss/ss	$30,000	$40,000	3	1.1	6	$240,000	$480,000
E-802 A/B	Atmospheric Column Preheat	2	Surface Area: 35 m2 Heat Duty: 2820 kW MOC (shell/tube): cs/ss	$9,500	$13,000	1.7	1	4	$51,000	$100,000
E-803 A/B	C3-C4 Heater	2	Surface Area: 1 m2 Heat Duty: 8 kW MOC (shell/tube): cs/ss	$2,000	$2,700	1.7	1	4	$11,000	$21,000
E-804 A/B	Fatty Acid Decarbox Heater	2	Surface Area: 6 m2 Heat Duty: 200 kW MOC (shell/tube): ss/ss	$4,000	$5,400	3	1.1	6	$32,000	$64,000
E-901 A/B	Atmospheric Reboiler	2	Surface Area: 140 m2 Heat Duty: 6800 kW MOC (shell/tube): cs/ss	$18,000	$24,000	1.7	1	4	$97,000	$190,000

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Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-902 A/B	Vacuum Column Reboiler	2	Surface Area: 140 m2 Heat Duty: 1910 kW MOC (shell/tube): cs/ss	$18,000	$24,000	1.7	1	4	$97,000	$190,000
E-903 A/B	Jet Diesel Cut Reboiler	2	Surface Area: 120 m2 Heat Duty: 3650 kW MOC (shell/tube): cs/ss	$12,000	$16,000	1.7	1	4	$64,000	$130,000
E-904 A/B	Hexane Splitter Column	2	Surface Area: 24 m2 Heat Duty: 1100 kW MOC (shell/tube): cs/ss	$6,500	$8,700	1.7	1	4	$35,000	$70,000
E-905 A/B	Naphtha Jet Reboiler	2	Surface Area: 42 m2 Heat Duty: 1140 kW MOC (shell/tube): cs/ss	$10,000	$13,000	1.7	1	4	$54,000	$110,000
E-906 A/B	Diesel Fuel Oil Cut Reboiler	2	Surface Area: 160 m2 Heat Duty: 2200 kW MOC (shell/tube): cs/ss	$20,000	$27,000	1.7	1	4	$110,000	$210,000
E-907 A/B	Syngas Column Reboiler	2	Surface Area: 14 m2 Heat Duty: 730 kW MOC (shell/tube): cs/ss	$6,000	$8,100	1.7	1.1	4.25	$34,000	$69,000
E-908 A/B	Debutanizer Reboiler	2	Surface Area: 8 m2 Heat Duty: 800 kW MOC (shell/tube): cs/ss	$5,000	$6,700	1.7	1.1	4.25	$29,000	$57,000
E-909 A/B	Water Removal Reboiler	2	Surface Area: 740 m2 Heat Duty: 5600 kW MOC (shell/tube): ss/ss	$50,000	$67,000	3	1	6	$400,000	$810,000
E-910 A/B	C2-C4 Column Reboiler	2	Surface Area: 130 m2 Heat Duty: 5800 kW MOC (shell/tube): ss/ss	$17,500	$24,000	3	1	6	$140,000	$280,000
E-911 A/B	Acetic Acid Column Reboiler	2	Surface Area: 110 m2 Heat Duty: 6600 kW MOC (shell/tube): ss/ss	$15,000	$20,000	3	1	6	$120,000	$240,000
E-912 A/B	C6-C7 Reboiler	2	Surface Area: 18 m2 Heat Duty: 1260 kW MOC (shell/tube): ss/ss	$6,000	$8,100	3	1	6	$48,000	$97,000

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Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-913 A/B	C4-C5 Reboiler	2	Surface Area: 4 m2 Heat Duty: 150 kW MOC (shell/tube): ss/ss	$3,000	$4,000	3	1	6	$24,000	$48,000
E-914 A/B	C3-C4 Reboiler	2	Surface Area: 2 m2 Heat Duty: 71 kW MOC (shell/tube): ss/ss	$2,000	$2,700	3	1	6	$16,000	$32,000
E-915 A/B	C5-C6 Product Reboiler	2	Surface Area: 15 m2 Heat Duty: 280 kW MOC (shell/tube): ss/ss	$6,000	$8,100	3	1	6	$48,000	$97,000
E-916 A/B	C8-C9 Reboiler	2	Surface Area: 26 m2 Heat Duty: 1900 kW MOC (shell/tube): ss/ss	$7,000	$9,400	3	1	6	$56,000	$110,000
E-917 A/B	C7-C8 Reboiler	2	Surface Area: 45 m2 Heat Duty: 760 kW MOC (shell/tube): ss/ss	$9,500	$13,000	3	1	6	$77,000	$150,000
E-918 A/B	C10-C11 Reboiler	2	Surface Area: 23 m2 Heat Duty: 1400 kW MOC (shell/tube): ss/ss	$6,000	$8,100	3	1	6	$48,000	$97,000
E-919 A/B	C9-C10 Reboiler	2	Surface Area: 81 m2 Heat Duty: 650 kW MOC (shell/tube): ss/ss	$12,500	$17,000	3	1	6	$100,000	$200,000
E-920 A/B	C11 Reboiler	2	Surface Area: 8 m2 Heat Duty: 560 kW MOC (shell/tube): ss/ss	$7,000	$9,400	3	1	6	$56,000	$110,000
E-1001 A/B	Naphtha Cooler	2	Surface Area: 100 m2 Heat Duty: 320 kW MOC (shell/tube): cs/cs	$15,000	$20,000	1	1	3	$60,000	$120,000
E-1002 A/B	Jet Cooler	2	Surface Area: 330 m2 Heat Duty: 1800 kW MOC (shell/tube): cs/cs	$35,000	$47,000	1	1	3	$140,000	$280,000
E-1003 A/B	Diesel Cooler 1	2	Surface Area: 140 m2 Heat Duty: 3600 kW MOC (shell/tube): cs/ss	$20,000	$27,000	1.7	1	4	$110,000	$210,000

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-1004 A/B	Diesel Cooler 2	2	Surface Area: 150 m2 Heat Duty: 280 kW MOC (shell/tube): cs/cs	$20,000	$27,000	1	1	3	$81,000	$160,000
E-1005 A/B	Fuel Oil Cooler	2	Surface Area: 3 m2 Heat Duty: 42 kW MOC (shell/tube): cs/ss	$ 4,000	$5,400	1.7	1	4	$21,000	$43,000
G-201 A/B	Flash 2 Compressor	2	Power: 17 kW Number of Stages: 1 MOC: Stainless Steel	From Quote	$18,000	1	1	2.5	$45,000	$91,000
G-202 A/B	Flash 3 Compressor	2	Power: 1 kW Number of Stages: 1 MOC: Carbon Steel	From Quote	$55	1	1	2.5	$140	$280
G-203	Light End Compressor	1	Power: 1500 kW Number of Stages: 3 MOC: Carbon Steel	From Quote	$1,600,000	1	1	2.5	$4,100,000	$4,100,000
L-201 A/B	PreCracking Pump	2	Power: 54 kW Suction Pressure: 110 kPa MOC: Stainless Steel	$17,500	$24,000	1.9	1	5	$120,000	$240,000
L-203 A/B	Post Extractor Pump	2	Power: 1 kW Suction Pressure: 140 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	6	$24,000	$48,000
L-204 A/B	Atmospheric Reflux	2	Power: 2 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	4	$27,000	$54,000
L-205 A/B	Vacuum Reflux	2	Power: 5 kW Suction Pressure: 7 kPa MOC: Carbon Steel	$6,000	$8,100	1.4	1	4	$32,000	$64,000
L-206 A/B	Vacuum Bottoms	2	Power: 1 kW Suction Pressure: 40 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-207 A/B	Naphtha Cut Pump	2	Power: 1 kW Suction Pressure: 130 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000

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Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-208 A/B	Flash 5 Pump	2	Power: 1 kW Suction Pressure: 102 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-209 A/B	Syngas Column Reflux	2	Power: 5 kW Suction Pressure: 3200 kPa MOC: Carbon Steel	$6,000	$8,100	1.4	1.75	6	$48,000	$97,000
L-210 A/B	Debutanizer Reflux	2	Power: 2 kW Suction Pressure: 790 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	4	$27,000	$54,000
L-211 A/B	Hexane Splitter Bottoms	2	Power: 1 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-212 A/B	Hexane Splitter Reflux	2	Power: 2 kW Suction Pressure: 90 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	4	$27,000	$54,000
L-213 A/B	Naphtha Reflux	2	Power: 5 kW Suction Pressure: 90 kPa MOC: Carbon Steel	$6,000	$8,100	1.4	1	4	$32,000	$64,000
L-214 A/B	Pre Jet Pump	2	Power: 2 kW Suction Pressure: 102 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	4	$27,000	$54,000
L-215 A/B	Jet Reflux	2	Power: 4 kW Suction Pressure: 68 kPa MOC: Carbon Steel	$5,500	$7,400	1.4	1	4	$30,000	$59,000
L-216 A/B	Jet Bottoms	2	Power: 1 kW Suction Pressure: 110 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-217 A/B	Diesel Reflux	2	Power: 8 kW Suction Pressure: 102 kPa MOC: Carbon Steel	$8,000	$11,000	1.4	1	4	$43,000	$86,000
L-218 A/B	Water Removal Reflux	2	Power: 5 kW Suction Pressure: 14 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-219 A/B	Water Removal Bottoms	2	Power: 1 kW Suction Pressure: 69 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-220 A/B	Solvent Recycle Pump	2	Power: 2 kW Suction Pressure: 69 kPa MOC: Stainless Steel	$5,000	$6,700	1.9	1	5	$34,000	$67,000
L-221 A/B	Acetic Acid Reflux	2	Power: 6 kW Suction Pressure: 69 kPa MOC: Stainless Steel	$7,000	$9,400	1.9	1	5	$47,000	$94,000
L-222 A/B	C3 Bottoms	2	Power: 1 kW Suction Pressure: 14 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-223 A/B	C3 Reflux	2	Power: 5 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-224 A/B	C6-C7 Reflux	2	Power: 7 kW Suction Pressure: 69 kPa MOC: Stainless Steel	$7,500	$10,000	1.9	1	5	$50,000	$100,000
L-225 A/B	C6-C7 Bottoms	2	Power: 1 kW Suction Pressure: 116 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-226 A/B	C4-C5 Reflux	2	Power: 7 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$7,500	$10,000	1.9	1	5	$50,000	$100,000
L-227 A/B	C4-C5 Bottoms	2	Power: 1 kW Suction Pressure: 55 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-228 A/B	C3-C4 Reflux	2	Power: 6 kW Suction Pressure: 34 kPa MOC: Stainless Steel	$7,000	$9,400	1.9	1	5	$47,000	$94,000
L-229 A/B	C3-C4 Bottoms	2	Power: 1 kW Suction Pressure: 55 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-230 A/B	C5-C6 Bottoms	2	Power: 1 kW Suction Pressure: 82 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-231 A/B	C5-C6 Reflux	2	Power: 6 kW Suction Pressure: 62 kPa MOC: Stainless Steel	$7,000	$9,400	1.9	1	5	$47,000	$94,000
L-232 A/B	C8-C9 Bottoms	2	Power: 1 kW Suction Pressure: 41 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-233 A/B	C8-C9 Reflux	2	Power: 5 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-234 A/B	C7-C8 Bottoms	2	Power: 1 kW Suction Pressure: 34 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-235 A/B	C7-C8 Reflux	2	Power: 5 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-236 A/B	C10-C11 Bottoms	2	Power: 1 kW Suction Pressure: 14 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-237 A/B	C10-C11 Reflux	2	Power: 6 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$7,000	$9,400	1.9	1	5	$47,000	$94,000
L-238 A/B	C9-C10 Reflux	2	Power: 5 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-239 A/B	C9-10 Bottoms	2	Power: 1 kW Suction Pressure: 14 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-240 A/B	C11 Reflux	2	Power: 5 kW Suction Pressure: 4 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-241 A/B	C11 Bottoms	2	Power: 7 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$7,500	$10,000	1.9	1	5	$50,000	$100,000
L-242 A/B	Jet Product	2	Power: 1 kW Suction Pressure: 69 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-243 A/B	Diesel Product	2	Power: 1 kW Suction Pressure: 102 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-244 A/B	C9-C10 Reflux	2	Power: 5 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-245 A/B	Post Extractor Pump 2	2	Power: 1 kW Suction Pressure: 102 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-246 A/B	Atmospheric Top Pump	2	Power: 2 kW Suction Pressure: 96 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	4	$27,000	$54,000
L-247 A/B	Vacuum Top Pump	2	Power: 3 kW Suction Pressure: 7 kPa MOC: Carbon Steel	$4,000	$5,400	1.4	1	4	$21,000	$43,000
L-248 A/B	Naphtha Product	2	Power: 1 kW Suction Pressure: 102 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-249 A/B	C2-C4 Split Top	2	Power: 1 kW Suction Pressure: 3 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-250 A/B	C4-C5 Split Top	2	Power: 1 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-251 A/B	C3-C4 Product Top	2	Power: 1 kW Suction Pressure: 34 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-252 A/B	C5-C6 Product Top	2	Power: 1 kW Suction Pressure: 161 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-253 A/B	C8-C9 Split Top	2	Power: 1 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-254 A/B	C7-C8 Product Top	2	Power: 1 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-255 A/B	C10-C11 Split Top	2	Power: 1 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-256 A/B	C9-C10 Split Top	2	Power: 1 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-257 A/B	C11 Top	2	Power: 2.5 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$5,500	$7,400	1.9	1	5	$37,000	$74,000
L-258 A/B	Flash 3 Pump	2	Power: 1 kW Suction Pressure: 105 kPa MOC: Carbon Steel	3000	$4,000	1.4	1	4	$16,000	$32,000
L-259 A/B	Pre Jet Pump 2	2	Power: 1 kW Suction Pressure: 104 kPa MOC: Carbon Steel	3000	$4,000	1.4	1	4	$16,000	$32,000
P-201	Refrigeration System	1	Load: 820-890 metric tons Power: 200 Volts	From Quote	$1,800,000	1	1	3.2	$5,900,000	$5,900,000
Q-201	TTCR Boiler	1	Duty: 64,000 kW	From Quote	$2,000,000	1	1	3.2	$6,500,000	$6,500,000
Q-202	High Pressure Steam Boiler	1	Duty: 41,000 kW	From Quote	$1,600,000	1	1	3.2	$5,000,000	$5,000,000

(continued)

Table 110. Broad cost estimate for fatty acid recovery design with integrated soybean oil processing plant cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
R-201	TTCR	1	Diameter: 6.1 m Length: 12.2 m Tubes: 10300 MOC: cs/inconel	From Quote	$30,000,000	0.7	1	3.2	$21,000,000	$21,000,000
R-202 A/B	Fatty Acid Decarboxylation Reactor	2	Diameter: 1.8 m Length: 11.2 m MOC: Stainless Steel Clad	From Quote	$390,000	1	1	3.2	$390,000	$780,000
	Extraction, Solvent Recovery, MOS, and Work Tank Sections	1	Capacity: 7500 MTPD	$17,850,000	$18,000,000	0.9	1	1	$16,000,000	$16,000,000
	Prep and Pelletizing Sections	1	Capacity: 7500 MTPD	$10,000,000	$9,900,000	1	1	1	$9,900,000	$9,900,000

Total Bare Module Cost	**CTBM**	$98,000,000
Contingency and Fees	**CTBM*0.18**	$18,000,000
Total Module Cost	**CTM**	$120,000,000
Auxiliary Facilities	**CTM*0.2**	$23,000,000
Fixed Capital Investment	**FCI**	$140,000,000
Working Capital	**FCI*0.15**	$21,000,000
Chemicals & Catalysts		$2,700,000
Total Capital Investment	**TCI**	$160,000,000

Notes: Actual numbers may be off due to rounding

Table 111. Operating expense summary for fatty acid recovery design with integrated soybean oil processing plant.

Year	Chemicals and Catalysts	Operating Labor	Maintenance	Utilities	Yearly Total
1	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000
2	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000
3	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000
4	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000
5	$2,300,000	$5,900,000	$8,300,000	$33,000,000	$50,000,000
6	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000
7	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000
8	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000
9	$2,300,000	$5,900,000	$8,300,000	$33,000,000	$50,000,000
10	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000
11	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000
12	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000
13	$2,300,000	$5,900,000	$8,300,000	$33,000,000	$50,000,000
14	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000
15	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000
16	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000
17	$2,300,000	$5,900,000	$8,300,000	$33,000,000	$50,000,000
18	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000
19	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000
20	$270,000	$5,900,000	$8,300,000	$33,000,000	$48,000,000

Notes: Actual numbers may be off due to rounding

Table 112. Cash flow sheet for fatty acid recovery design with integrated soybean oil processing plant.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR	Present Value @ DCFROR
-1	$-	$-	$-	$-	$-	$-	$-	($69,000)	($69,000)	($78,000)	($150,000)
0	$-	$-	$-	$-	$-	$-	$-	($93,000)	($93,000)	($93,000)	($93,000)
1	$1,400,000	$860,000	$48,000	$470,000	($19,000)	$450,000	($190,000)		$280,000	$250,000	$130,000
2	$1,400,000	$860,000	$48,000	$470,000	($17,000)	$460,000	($190,000)		$280,000	$230,000	$60,000
3	$1,400,000	$860,000	$48,000	$470,000	($15,000)	$460,000	($190,000)		$280,000	$200,000	$28,000
4	$1,400,000	$860,000	$48,000	$470,000	($13,000)	$460,000	($190,000)		$280,000	$180,000	$13,000
5	$1,400,000	$860,000	$50,000	$470,000	($12,000)	$460,000	($190,000)		$280,000	$160,000	$5,900
6	$1,400,000	$860,000	$48,000	$470,000	($10,000)	$460,000	($190,000)		$280,000	$140,000	$2,700
7	$1,400,000	$860,000	$48,000	$470,000	($9,000)	$460,000	($190,000)		$280,000	$130,000	$1,300
8	$1,400,000	$860,000	$48,000	$470,000	($8,000)	$460,000	($190,000)		$280,000	$110,000	$580
9	$1,400,000	$860,000	$50,000	$470,000	($7,000)	$460,000	($190,000)		$280,000	$100,000	$270
10	$1,400,000	$860,000	$48,000	$470,000	($6,600)	$470,000	($190,000)		$280,000	$90,000	$120
11	$1,400,000	$860,000	$48,000	$470,000	($6,600)	$470,000	($190,000)		$280,000	$80,000	$57
12	$1,400,000	$860,000	$48,000	$470,000	($6,600)	$470,000	($190,000)		$280,000	$72,000	$26
13	$1,400,000	$860,000	$50,000	$470,000	($6,600)	$460,000	($190,000)		$280,000	$64,000	$12
14	$1,400,000	$860,000	$48,000	$470,000	($6,600)	$470,000	($190,000)		$280,000	$57,000	$6
15	$1,400,000	$860,000	$48,000	$470,000	($6,600)	$470,000	($190,000)		$280,000	$51,000	$3
16	$1,400,000	$860,000	$48,000	$470,000	($6,600)	$470,000	($190,000)		$280,000	$46,000	$1
17	$1,400,000	$860,000	$50,000	$470,000	($6,600)	$460,000	($190,000)		$280,000	$41,000	$1
18	$1,400,000	$860,000	$48,000	$470,000		$470,000	($200,000)		$280,000	$36,000	$0
19	$1,400,000	$860,000	$48,000	$470,000		$470,000	($200,000)		$280,000	$32,000	$0
20	$1,400,000	$860,000	$48,000	$470,000		$470,000	($200,000)	$21,000	$300,000	$31,000	$0
									NPV@HR	$1,900,000	$0
									DCFROR	120%	
									HR	12%	

Notes: Dollar values are in thousands

Actual numbers may be off due to rounding

Numbers in parenthesis represent negative numbers

Table 113. Cash flow sheet for fatty acid recovery design with integrated soybean processing and a soybean price of $0.50/kg.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR
-1	$-	$-	$-	$-	$-	$-	$-	($69,000)	($69,000)	($78,000)
0	$-	$-	$-	$-	$-	$-	$-	($93,000)	($93,000)	($93,000)
1	$1,400,000	$1,300,000	$48,000	$31,000	($19,000)	$12,000	($4,900)		$26,000	$23,000
2	$1,400,000	$1,300,000	$48,000	$31,000	($17,000)	$14,000	($5,900)		$25,000	$20,000
3	$1,400,000	$1,300,000	$48,000	$31,000	($15,000)	$16,000	($6,700)		$24,000	$17,000
4	$1,400,000	$1,300,000	$48,000	$31,000	($13,000)	$18,000	($7,400)		$24,000	$15,000
5	$1,400,000	$1,300,000	$50,000	$31,000	($12,000)	$17,000	($7,200)		$22,000	$12,000
6	$1,400,000	$1,300,000	$48,000	$29,000	($10,000)	$21,000	($8,600)		$22,000	$11,000
7	$1,400,000	$1,300,000	$48,000	$31,000	($9,000)	$22,000	($9,100)		$22,000	$9,900
8	$1,400,000	$1,300,000	$48,000	$31,000	($8,000)	$23,000	($9,600)		$21,000	$8,700
9	$1,400,000	$1,300,000	$50,000	$31,000	($7,000)	$22,000	($9,100)		$20,000	$7,200
10	$1,400,000	$1,300,000	$48,000	$29,000	($6,600)	$24,000	($10,000)		$21,000	$6,700
11	$1,400,000	$1,300,000	$48,000	$31,000	($6,600)	$24,000	($10,000)		$21,000	$6,000
12	$1,400,000	$1,300,000	$48,000	$31,000	($6,600)	$24,000	($10,000)		$21,000	$5,400
13	$1,400,000	$1,300,000	$50,000	$31,000	($6,600)	$22,000	($9,300)		$20,000	$4,500
14	$1,400,000	$1,300,000	$48,000	$29,000	($6,600)	$24,000	($10,000)		$21,000	$4,300
15	$1,400,000	$1,300,000	$48,000	$31,000	($6,600)	$24,000	($10,000)		$21,000	$3,800
16	$1,400,000	$1,300,000	$48,000	$31,000	($6,600)	$24,000	($10,000)		$21,000	$3,400
17	$1,400,000	$1,300,000	$50,000	$31,000	($6,600)	$22,000	($9,300)		$20,000	$2,900
18	$1,400,000	$1,300,000	$48,000	$29,000		$31,000	($13,000)		$18,000	$2,400
19	$1,400,000	$1,300,000	$48,000	$31,000		$31,000	($13,000)		$18,000	$2,100
20	$1,400,000	$1,300,000	$48,000	$31,000		$31,000	($13,000)	$21,000	$39,000	$4,000
									NPV@HR	$0
									DCFROR	12%
									HR	12%

Notes: Actual numbers may be off due to rounding

Dollar values are in thousands

Numbers in parenthesis represent negative numbers

Table 114. Cash flow sheet for fatty acid recovery design with integrated soybean processing and a soybean meal price of $0.26/kg.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR
-1	$-	$-	$-	$-	$-	$-	$-	($69,000)	($69,000)	($78,000)
0	$-	$-	$-	$-	$-	$-	$-	($93,000)	($93,000)	($93,000)
1	$940,000	$860,000	$48,000	$31,000	($19,000)	$12,000	($4,900)		$26,000	$23,000
2	$940,000	$860,000	$48,000	$31,000	($17,000)	$14,000	($5,900)		$25,000	$20,000
3	$940,000	$860,000	$48,000	$31,000	($15,000)	$16,000	($6,700)		$24,000	$17,000
4	$940,000	$860,000	$48,000	$31,000	($13,000)	$18,000	($7,400)		$24,000	$15,000
5	$940,000	$860,000	$50,000	$29,000	($12,000)	$17,000	($7,200)		$22,000	$12,000
6	$940,000	$860,000	$48,000	$31,000	($10,000)	$21,000	($8,600)		$22,000	$11,000
7	$940,000	$860,000	$48,000	$31,000	($9,000)	$22,000	($9,100)		$22,000	$9,900
8	$940,000	$860,000	$48,000	$31,000	($8,000)	$23,000	($9,600)		$21,000	$8,700
9	$940,000	$860,000	$50,000	$29,000	($7,000)	$22,000	($9,100)		$20,000	$7,200
10	$940,000	$860,000	$48,000	$31,000	($6,600)	$24,000	($10,000)		$21,000	$6,700
11	$940,000	$860,000	$48,000	$31,000	($6,600)	$24,000	($10,000)		$21,000	$6,000
12	$940,000	$860,000	$48,000	$31,000	($6,600)	$24,000	($10,000)		$21,000	$5,400
13	$940,000	$860,000	$50,000	$29,000	($6,600)	$22,000	($9,300)		$20,000	$4,500
14	$940,000	$860,000	$48,000	$31,000	($6,600)	$24,000	($10,000)		$21,000	$4,300
15	$940,000	$860,000	$48,000	$31,000	($6,600)	$24,000	($10,000)		$21,000	$3,800
16	$940,000	$860,000	$48,000	$31,000	($6,600)	$24,000	($10,000)		$21,000	$3,400
17	$940,000	$860,000	$50,000	$29,000	($6,600)	$22,000	($9,300)		$20,000	$2,900
18	$940,000	$860,000	$48,000	$31,000		$31,000	($13,000)		$18,000	$2,400
19	$940,000	$860,000	$48,000	$31,000		$31,000	($13,000)		$18,000	$2,100
20	$940,000	$860,000	$48,000	$31,000		$31,000	($13,000)	$21,000	$39,000	$4,000

NPV@HR	$0
DCFROR	12%
HR	12%

Notes: Actual numbers may be off due to rounding

Dollar values are in thousands

Numbers in parenthesis represent negative numbers

VI.B.3. Heavy end Processing with Integrated Soybean plant

VI.B.3.i. Broad Cost Estimate

The capital cost summary for the base design with mesophase pitch recovery and integrated soybean processing plant is shown in Table 115. This table shows the total capital investment needed to complete the project, and was developed as described in Chapter II. The FCI was found to be $140 million, and the TCI was estimated to be $180 million ± 40%.

VI.B.3.ii. Raw Material and Manufacturing Cost Estimate

The raw material cost is based on purchasing raw soybeans off the open market for $0.33/kg [60]. The total raw material cost is $860 million per year.

The total manufacturing cost for the base design with mesophase pitch recovery integrated with the soybean oil processing plant is $45 million per year, and $63 million per year on years the decarboxylate catalyst beds need to be replaced. The manufacturing cost includes chemicals and catalysts costs, operating labor costs, maintenance costs, and utility costs. Table 116 shows the overall yearly operating expense summary for the mesophase pitch recovery integrated with the soybean oil processing design. The plant has an operating factor of 95%. Intermediate results can be found in Appendix C, and communication records can be found in Appendix G.

The catalyst used for the decarboxylation reactors in the base design with mesophase pitch recovery was a Ni catalyst. The initial charge for the catalyst (shown on the broad cost estimate) covers the total amount of catalyst needed (530,000 kg) for a price of $19 million. This amount is charged every four years in order to recharge the catalyst. It was assumed there was a 4% yearly depletion of the catalyst that needed to be replaced for the in between years. This results in a cost of $750,000 for those years. A quote from Johnson Matthey Catalysts was used for pricing ($28/m3).

The chemicals needed for the soybean oil processing plant include mineral oil and hexane. The initial charge for the chemical (shown on the broad cost estimate) covers the total amount of solvents needed for the soybean oil extraction process (260,000 kg hexane and 140 kg of mineral oil) for a total price of $99,000. It was assumed there was a 17% yearly depletion that needed to be replaced. This resulted in a yearly cost of $55,000. Prices for the solvents were taken from “Soybean Oil Extraction Using Commercial Hexane” [56].

The base design with mesophase pitch recovery and integrated soybean oil processing consists of an equivalent of 53 major unit operations, which equates to 68 new operators to cover continuous operation, as described in Chapter II. An average operator salary of $62,800 was used, and taking into account an additional 15% for supervision, the yearly operating expense equates out to $4,900,000 per year [53]. The maintenance costs were found to be $8.6 million per year.

The utility costs is $30,000,000 per year. This value includes the boiler feed water, cooling water, electricity, refrigeration, process water, credit for the leftover syngas, and medium and high pressure steam. The steam was required for the soybean oil processing plant. The prices for all the utilities, except the electricity, were priced based off of Turton heuristics. The electricity values were found from typical ND and MN values [55].

VI.B.3.iii. Revenues

Revenue for the base design with mesophase pitch recovery and integrated soybean oil processing comes from the sales of jet fuel, diesel fuel no. 2, petroleum naphtha, butane, mesophase pitch, acetic acid, soybean meal, and pelleted hulls. Shipping costs were not considered when calculating the amount of revenues generated.

The transportation fuels, jet fuel, diesel fuel no. 2, and petroleum naphtha, produce a revenue of $140 million/year. This value was based on the production 120,000 liquid m3/year of petroleum naphtha that can be sold for $0.36/L, jet fuel at a rate of 170,000 liquid m3/year which is sold for $0.37/L, and diesel fuel no. 2 produced at 170,000 liquid m3/year and sold at $0.37/L. The remaining by products produce a revenue of $1.5 billion/year. Of this $1.5 billion, $510 million/year is from the sale of mesophase pitch, and $930 million is from the sale of soybean meal. The total annual revenue for the design is $1.6 billion/year.

VI.B.3.iv. Overall Profitability

The cash flow sheet for the base design with mesophase pitch recovery and integrated soybean oil processing is shown in Table 117. The process has a NPV@12% of $3 billion ± 40%. The project produces a gross income of $710 million per year, and has a DCFROR value of 150%. The positive NPV@12% value and a DCFROR value greater than 12% show that the investment is profitable over the project lifecycle.

VI.B.3.v. Break Even Point

Although a significant investment, with the current design and prices of products and raw materials the process recovers the initial investment within the first year. In order for the process to break even over the 20 year lifecycle, the price of soybeans would have to rise to a price of \$0.60/kg (\$16.20/bushel). This last happened in October, 2012, and is close to an all-time high for soybean prices. The cash flow sheet based on a soybean price of \$0.60/kg can be seen in Table 118.

In addition, the sale of mesophase pitch is not needed for the process to be profitable. It could drop to \$0/kg, and the process would still have a NPV@12% of \$710 million ± 40 %. The saleable byproduct of soybean meal could potentially affect the profitability of the process. The price of meal would have to drop to \$0.13/kg (\$120/ton) for the process to break even, which would be an all-time low for soybean meal. The cash flow sheet based on a soybean meal price of \$0.13/kg can be seen in Table 119.

Table 115. Broad cost estimate for base design with mesophase pitch recovery and integrated soybean oil processing.

Equipment	Equipment Description	Number	Capacity/Size Specs	Purchased Equipment Cost: Year 2004	Purchased Equipment Cost: Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
C-101 A/B	Mesophase Pitch Crusher	2	Capacity : 100 kg/min Power: 1.3 kW MOC: Carbon Steel	$10,000	$13,000	1	1	2.1	$28,000	$56,000
D-101	Flash 1	1	Height: 5.8 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$11,750	$16,000	2.5	1	7	$110,000	$110,000
D-102	Flash 2	1	Height: 5.3 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$11,500	$15,000	2.5	1	7	$110,000	$110,000
D-103	Flash 3	1	Height: 4.9 m Inside Diameter: 1.2m Vertical Orientation MOC: Carbon Steel	$11,000	$15,000	1	2	6	$89,000	$89,000
D-104	Flash 4	1	Height: 4.7 m Inside Diameter: 1.2 m Vertical Orientation MOC: Carbon Steel	$11,000	$15,000	1	1	4	$59,000	$59,000
D-105	Flash 5	1	Height: 5.4 m Inside Diameter: 1.4 m Vertical Orientation MOC: Carbon Steel	$10,000	$13,000	1	1	4	$54,000	$54,000

(continued)

Table 115. Broad cost estimate for base design with mesophase pitch recovery and integrated soybean oil processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-107	Acetic Flash 1	1	Length: 1.8 m Inside Diameter: 0.5 m Horizontal Orientation MOC: Stainless Steel Clad	$1,500	$2,000	2.5	1.5	8	$16,000	$16,000
D-108	Acetic Flash 2	1	Length: 3.4 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$5,000	$6,700	2.5	1	7	$47,000	$47,000
D-109	Flash 7	1	Height: 2.7 m Inside Diameter: 0.7 m Vertical Orientation MOC: Carbon Steel	$3,000	$4,000	1	1	4	$16,000	$16,000
D-201	Atmospheric Column	1	Height: 8.4 m Diameter: 2.4 m Trays: 7 Feed: Tray 3 MOC: Stainless Steel Clad	$40,000	$54,000	2.5	1	7	$380,000	$380,000
D-201 Trays	Atmospheric Column Trays	7	Diameter: 2.4 m MOC: Stainless Steel	From Quote	$2,500	1	1	1.2	$3,000	$21,000
D-202	Vacuum Colum	1	Height: 20 m Diameter: 2.9 m Trays: 20 Feed: Tray 5 MOC: Stainless Steel Clad	$70,000	$94,000	2.5	1	7	$660,000	$660,000
D-202 Trays	Vacuum Column Trays	20	Diameter: 2.9 m MOC: Stainless Steel	From Quote	$2,800	1	1	1.2	$2,800	$56,000

(continued)

Table 115. Broad cost estimate for base design with mesophase pitch recovery and integrated soybean oil processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-204	Jet Diesel Cut	1	Height: 24 m Diameter: 2.6 m Trays: 25 Feed: Tray 13 MOC: Carbon Steel	$50,000	$67,000	1	1	4	$270,000	$270,000
D-204 Trays	Jet Diesel Cut Trays	25	Diameter: 2.6 m MOC: Stainless Steel	From Quote	$2,600	1	1.025	1.2	$3,200	$81,000
D-205	Naphtha-Jet Cut	1	Height: 27.5 m Diameter: 1.7 m Trays: 30 Feed: Tray 7 MOC: Carbon Steel	$80,000	$110,000	1	1	4	$430,000	$430,000
D-205 Trays	Naphtha-Jet Cut Trays	30	Diameter: 1.7 m MOC: Stainless Steel	From Quote	$2,100	1	1	1.2	$2,500	$76,000
D-206	Diesel-Fuel Oil Cut	1	Height: 37 m Diameter: 2.8 m Trays: 40 Feed: Tray 28 MOC: Carbon Steel	$150,000	$200,000	1	1	4	$810,000	$810,000
D-206 Trays	Diesel-Fuel Oil Cut Trays	40	Diameter: 2.8 m MOC: Stainless Steel	From Quote	$2,800	1	1	1.2	$3,300	$130,000
D-207	Syngas Column	1	Height: 37 m Diameter: 2.7 m Trays: 40 Feed: Tray 5 MOC: Carbon Steel	$125,000	$170,000	1	3	8	$1,300,000	$1,300,000

(continued)

Table 115. Broad cost estimate for base design with mesophase pitch recovery and integrated soybean oil processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-207 Trays	Syngas Trays	40	Diameter: 2.7 m MOC: Stainless Steel	From Quote	$2,700	1	1	1.2	$3,300	$130,000
D-210	Debutanizer	1	Height: 11.5 m Diameter: 2.1 m Trays: 12 Feed: Tray 8 MOC: Carbon Steel	$45,000	$60,000	1	2	6	$360,000	$360,000
D-210 Trays	Debutanizer Trays	12	Diameter: 2.1 m MOC: Stainless Steel	From Quote	$2,300	1	1.18	1.2	$3,300	$40,000
D-301	Atmospheric Column Reflux Drum	1	Length: 3 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$4,000	$5,400	2.5	1	4	$21,000	$21,000
D-302	Vacuum Column Reflux Drum	1	Length: 5.5 m Inside Diameter: 1.4 m Horizontal Orientation MOC: Stainless Steel Clad	7000	$9,400	2.5	1	4	$38,000	$38,000
D-304	Jet-Diesel Cut Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	$4,000	$5,400	1	1	3	$16,000	$16,000
D-305	Naphtha-Jet Cut Reflux Drum	1	Length: 3 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	4000	$5,400	1	1	3	$16,000	$16,000
D-306	Diesel-Fuel Oil Cut Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	$6,000	$8,100	1	1	3	$24,000	$24,000

(continued)

Table 115. Broad cost estimate for base design with mesophase pitch recovery and integrated soybean oil processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-307	Syngas Column Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	6000	$8,100	1	1	3	$24,000	$24,000
D-308	Debutanizer Reflux Drum	1	Length: 3.7 m Inside Diameter: 0.9 m Horizontal Orientation MOC: Carbon Steel	$5,500	$7,400	1	1	3	$22,000	$22,000
D-310	Acetic Acid Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Stainless Steel Clad	2500	$3,400	2.5	1	4	$13,000	$13,000
D-311	Naphtha Drum	1	Length: 3.7 m Inside Diameter: 0.9 m Horizontal Orientation MOC: Carbon Steel	$5,500	$7,400	1	1	3	$22,000	$22,000
D-312	Flash 7 Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Stainless Steel Clad	6000	$8,100	2.5	1	4	$32,000	$32,000
D-505 A/B	Stage 1 Light End Knockout Drum	2	Height: 3.6 m Inside Diameter: 1.2 m Horizontal Orientation MOC: Carbon Steel	$10,000	$13,000	1	1	4	$54,000	$110,000
D-506 A/B	Stage 2 Light End Knockout Drum	2	Height: 1.9 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Carbon Steel	4000	$5,400	1	1	4	$21,000	$43,000

(continued)

Table 115. Broad cost estimate for base design with mesophase pitch recovery and integrated soybean oil processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-507 A/B	Stage 3 Light End Knockout Drum	2	Height: 1.0 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Carbon Steel	$2,000	$2,700	1	1	4	$11,000	$21,000
E-101 A/B	Atmospheric Column Condenser	2	Surface Area: 660 m2 Heat Duty: 2500 kW MOC (shell/tube): cs/ss	55000	$74,000	1.7	1	4	$130,000	$250,000
E-102 A/B	Vacuum Column Condenser	2	Surface Area: 55 m2 Heat Duty: 5500 kW MOC (shell/tube): cs/ss	$11,000	$15,000	1.7	1	4	$59,000	$120,000
E-103 A/B	Jet Diesel Cut Condenser	2	Surface Area: 340 m2 Heat Duty: 2900 kW MOC (shell/tube): cs/ss	32000	$43,000	1.7	1	4	$170,000	$340,000
E-104 A/B	Syngas Condenser	2	Surface Area: 75 m2 Heat Duty: 580 kW MOC (shell/tube): cs/cs	$12,000	$16,000	1	1	3.2	$52,000	$100,000
E-105 A/B	Naphtha Jet Condenser	2	Surface Area: 500 m2 Heat Duty: 1600 kW MOC (shell/tube): cs/cs	45000	$60,000	1	1.1	3.2	$190,000	$390,000
E-106 A/B	Debutanizer Condenser	2	Surface Area: 44 m2 Heat Duty: 760 kW MOC (shell/tube): cs/cs	$9,500	$13,000	1	1	3.2	$41,000	$82,000
E-107 A/B	Diesel-Fuel Oil Cut Condenser	2	Surface Area: 15 m2 Heat Duty: 2200 kW MOC (shell/tube): cs/cs	4000	$5,400	1	1	3.2	$17,000	$34,000
E-201 A/B	Cracking Cross Exchanger	2	Surface Area: 320 m2 Heat Duty: 14,000 kW MOC (shell/tube): cs/ss	$30,000	$40,000	1.7	1	4	$160,000	$320,000

(continued)

Table 115. Broad cost estimate for base design with mesophase pitch recovery and integrated soybean oil processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-202 A/B	Flash 2 Cooler	2	Surface Area: 170 m2 Heat Duty: 2700 kW MOC (shell/tube): cs/ss	15000	$20,000	1.7	1.25	4	$81,000	$160,000
E-204 A/B	Light End Cooler	2	Surface Area: 360 m2 Heat Duty: 1400 kW MOC (shell/tube): cs/cs	$35,000	$47,000	1	1.1	3.25	$150,000	$310,000
E-205 A/B	Debutanizer Cooler	2	Surface Area: 16 m2 Heat Duty: 340 kW MOC (shell/tube): cs/cs	4000	$5,400	1	1	3.2	$17,000	$34,000
E-207 A/B	Pre-Flash 5 Cooler	2	Surface Area: 41 m2 Heat Duty: 400 kW MOC (shell/tube): cs/ss	$9,500	$13,000	1.7	1	4	$51,000	$100,000
E-208 A/B	Post Diesel Decarbox Cooler	2	Surface Area: 33 m2 Heat Duty: 2800 kW MOC (shell/tube): cs/cs	$8,000	$11,000	1	1	3.2	$34,000	$69,000
E-209 A/B	Post Naphtha Decarbox Cooler	2	Surface Area: 74 m2 Heat Duty: 3600 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3.2	$43,000	$86,000
E-210 A/B	Interstage Cooler 1	2	Surface Area: 210 m2 Heat Duty: 750 kW MOC (shell/tube): cs/ss	$22,500	$30,000	1.7	1	4	$120,000	$240,000
E-211 A/B	Interstage Cooler 2	2	Surface Area: 130 m2 Heat Duty: 890 kW MOC (shell/tube): cs/ss	$14,000	$19,000	1.7	1	4	$75,000	$150,000
E-401 A/B	Atmospheric Column Reboiler	2	Surface Area: 200 m2 Heat Duty: 7300 kW MOC (shell/tube): ss clad/ss	$22,500	$30,000	3	1.1	6	$180,000	$360,000

(continued)

Table 115. Broad cost estimate for base design with mesophase pitch recovery and integrated soybean oil processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-402 A/B	Vacuum Column Reboiler	2	Surface Area: 840 m2 Heat Duty: 4300 kW MOC (shell/tube): ss clad/ss	$60,000	$81,000	3	1.1	6	$480,000	$970,000
E-403 A/B	Naphtha Jet Cut Reboiler	2	Surface Area: 100 m2 Heat Duty: 2400 kW MOC (shell/tube): cs/ss	$12,000	$16,000	1.7	1	4	$64,000	$130,000
E-404 A/B	Jet Diesel Cut Reboiler	2	Surface Area: 170 m2 Heat Duty: 3500 kW MOC (shell/tube): cs/ss	$20,000	$27,000	1.7	1.1	4.5	$120,000	$240,000
E-405 A/B	Syngas Column Reboiler	2	Surface Area: 19 m2 Heat Duty: 1000 kW MOC (shell/tube): cs/ss	$8,000	$11,000	1.7	1.1	4.5	$48,000	$97,000
E-407 A/B	Debutanizer Reboiler	2	Surface Area: 11 m2 Heat Duty: 900 kW MOC (shell/tube): cs/ss	$4,000	$5,400	1.7	1.1	4.5	$24,000	$48,000
E-409 A/B	Diesel Fuel Oil Cut Reboiler	2	Surface Area: 200 m2 Heat Duty: 2200 kW MOC (shell/tube): cs/ss	$25,000	$34,000	1.7	1.1	4.5	$150,000	$300,000
E-502 A/B	TTCT Preheat	2	Surface Area: 460 m2 Heat Duty: 6300 kW MOC (shell/tube): ss clad /ss	$40,000	$54,000	3	1.25	7	$380,000	$750,000
E-503 A/B	Naphtha Decarbox Heater	2	Surface Area: 43 m2 Heat Duty: 3700 kW MOC (shell/tube): cs/ss	$10,000	$13,000	1.7	1.1	4.5	$60,000	$120,000
E-504 A/B	Diesel Decarbox Heater	2	Surface Area: 41 m2 Heat Duty: 1800 kW MOC (shell/tube): cs/ss	$10,000	$13,000	1.7	1.1	4.5	$60,000	$120,000

(continued)

Table 115. Broad cost estimate for base design with mesophase pitch recovery and integrated soybean oil processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-505 A/B	Pre Jet Diesel Cut Heat	2	Surface Area: 22 m2 Heat Duty: 540 kW MOC (shell/tube): cs/cs	$6,000	$8,100	1	1	3.2	$26,000	$52,000
E-506 A/B	Pitching Preheat	2	Surface Area: 120 m2 Heat Duty: 2400 kW MOC (shell/tube): ss clad/ss	$13,500	$18,000	3	1.25	7	$130,000	$250,000
E-1101 A/B	Jet Cooler	2	Surface Area: 260 m2 Heat Duty: 1200 kW MOC (shell/tube): cs/cs	$27,500	$37,000	1	1	3.2	$120,000	$240,000
E-1102 A/B	Diesel Cooler	2	Surface Area: 130 m2 Heat Duty: 3000 kW MOC (shell/tube): cs/cs	$14,000	$19,000	1	1	3.2	$60,000	$120,000
E-1103 A/B	Fuel Oil Cooler 1	2	Surface Area: 6 m2 Heat Duty: 80 kW MOC (shell/tube): cs/cs	$3,000	$4,000	1	1	3.2	$13,000	$26,000
E-1104 A/B	Fuel Oil Cooler 2	2	Surface Area: 690 m2 Heat Duty: 4400 kW MOC (shell/tube): cs/ss	$50,000	$67,000	1.7	1.1	4.5	$300,000	$600,000
G-101 A/B	Flash 2 Compressor	2	Power: 17 kW Number of Stages: 1 MOC: Stainless Steel	From Quote	$18,000	1	1	2.52	$46,000	$91,000
G-103 A/B	Flash 5 Compressor	2	Power: 15 kW Number of Stages: 1 MOC: Carbon Steel	From Quote	$16,000	1	1	2.5	$41,000	$81,000
G-105	Light End Compressor	1	Power: 1900 kW Number of Stages: 3 MOC: Carbon Steel	From Quote	$2,000,000	1	1	2.5	$5,000,000	$5,000,000
J-101 A/B	Pitch Reactor Product Screw Conveyor	2	Length: 6 m Width: 1.5 m	$12,500	$17,000	1	1	2.4	$40,000	$81,000

(continued)

Table 115. Broad cost estimate for base design with mesophase pitch recovery and integrated soybean oil processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
J-101 A/B - Motor	Pitch Reactor Product Screw Conveyor Motor	2	Power: 870 W	$300	$400	1	1	2	$810	$1,600
J-102 A/B	Crusher Feed Belt Conveyor	2	Length: 3 m Width: 1.5 m	$10,000	$13,000	1	1	2.4	$32,000	$64,000
J-102 A/B - Motor	Pitch Reactor Product Screw Conveyor Motor	2	Power: 430 W	$250	$340	1	1	2	$670	$1,300
J-103 A/B	Mesophase Pitch Belt Conveyor	2	Length: 3 m Width: 1.5 m	$10,000	$13,000	1	1	2.4	$32,000	$64,000
J-103 A/B - Motor	Pitch Reactor Product Screw Conveyor Motor	2	Power: 430 W	$250	$340	1	1	2	$670	$1,300
L-101 A/B	PreCracking Pump	2	Power: 70 kW Suction Pressure: 110 kPa MOC: Stainless Steel	$12,500	$17,000	1.9	1	4.5	$76,000	$150,000
L-103 A/B	Pre Naphtha Decarbox	2	Power: 17 kW Suction Pressure: 120 kPa MOC: Stainless Steel	$10,000	$13,000	1.9	1	4.5	$60,000	$120,000
L-104 A/B	Atmospheric Reflux	2	Power: 1.6 kW Suction Pressure: 100 kPa MOC: Stainless Steel	$4,000	$5,400	1.9	1	3.2	$17,000	$34,000
L-105 A/B	Atmospheric Bottoms	2	Power: 810 W Suction Pressure: 110 kPa MOC: Stainless Steel	$3,900	$5,200	1.9	1	3.2	$17,000	$34,000
L-106 A/B	Vacuum Column Bottom	2	Power: 4.3 kW Suction Pressure: 33 kPa MOC: Stainless Steel	$5,000	$6,700	1.9	1	3.2	$21,000	$43,000
L-107 A/B	Vacuum Bottoms	2	Power: 760 W Suction Pressure: 100 kPa MOC: Stainless Steel	$3,800	$5,100	1.9	1	3.2	$16,000	$33,000

(continued)

Table 115. Broad cost estimate for base design with mesophase pitch recovery and integrated soybean oil processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-108 A/B	Vacuum Reflux	2	Power: 5.1 kW Suction Pressure: 100 kPa MOC: Stainless Steel	$5,500	$7,400	1.9	1	3.2	$24,000	$47,000
L-109 A/B	PreDiesel Decarbox	2	Power: 29 kW Suction Pressure: 120 kPa MOC: Stainless Steel	$10,750	$14,000	1.9	1	4.5	$65,000	$130,000
L-110 A/B	PreJet-Diesel Cut Heat Pump	2	Power: 1.1 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$4,000	$5,400	1.4	1	3.2	$17,000	$34,000
L-111 A/B	Naphtha Product	2	Power: 200 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,200	$4,300	1.4	1	3.2	$14,000	$28,000
L-112 A/B	Jet Diesel Cut Reflux	2	Power: 4.4 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$5,250	$7,100	1.4	1	3.2	$23,000	$45,000
L-113 A/B	Jet Diesel Cut Bottoms	2	Power: 530 W Suction Pressure: 120 kPa MOC: Carbon Steel	$3,500	$4,700	1.4	1	3.2	$15,000	$30,000
L-114 A/B	Diesel Fuel Oil Cut Reflux	2	Power: 6.7 kW Suction Pressure: 100 kPa MOC: Stainless Steel	$8,500	$11,000	1.9	1	3.2	$37,000	$73,000
L-115 A/B	Diesel Fuel Oil Cut Bottoms	2	Power: 31 W Suction Pressure: 140 kPa MOC: Stainless Steel	$2,500	$3,400	1.9	1	3.2	$11,000	$21,000
L-116 A/B	Flash 5 Pump	2	Power: 48 W Suction Pressure: 100 kPa MOC: Stainless Steel	$2,750	$3,700	1.9	1	3.2	$12,000	$24,000

(continued)

Table 115. Broad cost estimate for base design with mesophase pitch recovery and integrated soybean oil processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-118 A/B	Jet Fuel Product	2	Power: 540 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,500	$4,700	1.4	1	3.2	$15,000	$30,000
L-119 A/B	Naphtha Jet Reflux	2	Power: 5.0 kW Suction Pressure: 110 kPa MOC: Carbon Steel	$5,250	$7,100	1.4	1	3.2	$23,000	$45,000
L-120 A/B	Naphtha Jet Bottoms	2	Power: 510 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,250	$4,400	1.4	1	3.2	$14,000	$28,000
L-121 A/ B	Debutanizer reflux	2	Power: 1.7 kW Suction Pressure: 820 kPa MOC: Carbon Steel	$4,200	$5,600	1.4	1	3.2	$18,000	$36,000
L-127 A/B	Syngas Reflux	2	Power: 6 kW Suction Pressure: 2700 kPa MOC: Carbon Steel	$5,500	$7,400	1.4	1	3.2	$24,000	$47,000
L-128 A/B	Flash 7 Pump	2	Power: 250 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,300	$4,400	1.4	1	3.2	$14,000	$28,000
L-129 A/B	Diesel Product	2	Power: 330 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,400	$4,600	1.4	1	3.2	$15,000	$29,000
L-130 A/B	Fuel Oil Pump	2	Power: 790 W Suction Pressure: 7 kPa MOC: Carbon Steel	$3,850	$5,200	1.4	1	3.2	$17,000	$33,000
L-131 A/B	Carbon Fiber Pump	2	Power: 170 W Suction Pressure: 7 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	3.2	$13,000	$26,000
P-101	Refrigeration System	1	Load: 820-890 metric tons Power: 200 Volts	From Quote	$1,800,000	1	1	3.2	$5,900,000	$5,900,000
Q-101	TTCR Boiler	1	Duty: 65,000 kW	From Quote	$2,100,000	1	1	3.2	$6,700,000	$6,700,000

(continued)

Table 115. Broad cost estimate for base design with mesophase pitch recovery and integrated soybean oil processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
Q-102	High Pressure Steam Boiler	1	Duty: 78,000 kW	From Quote	$2,300,000	1	1	3.2	$7,400,000	$7,400,000
R-101	TTCR	1	Diameter: 6.1 m Length: 12.2 m Tubes: 10300 MOC: cs/inconel	From Quote	$30,000,000	0.7	1	3.2	$21,000,000	$21,000,000
R-102 A/B	Naphtha Decarboxylation Reactor	2	Diameter: 2.9 m Length: 17 m MOC: Stainless Steel Clad	From Quote	$840,000	1	1	3.2	$2,700,000	$5,400,000
R-103 A/B	Diesel Decarboxylation Reactor	2	Diameter: 3.2 m Length: 19 m MOC: Stainless Steel Clad	From Quote	$1,000,000	1	1	3.2	$3,300,000	$6,700,000
R-104 A/B	Pitching Reactor	2	Diameter: 1.2 m Height: 3.6 m MOC: Stainless Steel Clad	$360,000	$480,000	1	1	3.2	$1,500,000	$3,100,000
	Extraction, Solvent Recovery, MOS, and Work Tank Sections	1	Capacity: 7500 MTPD	$17,850,000	$18,000,000	0.9	1	1	$16,000,000	$16,000,000
	Prep and Pelletizing Sections	1	Capacity: 7500 MTPD	$10,000,000	$9,900,000	1	1	1	$9,900,000	$9,900,000

Total Bare Module Cost	CTBM	$100,000,000
Contingency and Fees	CTBM*0.18	$18,000,000
Total Module Cost	CTM	$120,000,000
Auxiliary Facilities	CTM*0.2	$24,000,000
Fixed Capital Investment	FCI	$140,000,000
Working Capital	FCI*0.15	$22,000,000
Chemicals & Catalysts		$19,000,000
Total Capital Investment	TCI	$180,000,000

Notes: Actual numbers may be off due to rounding

Table 116. Operating expense summary for base design with mesophase pitch and integrated soybean oil processing.

Year	Chemicals and Catalysts	Operating Labor	Maintenance	Utilities	Yearly Total
1	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000
2	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000
3	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000
4	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000
5	$19,000,000	$4,900,000	$8,600,000	$30,000,000	$63,000,000
6	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000
7	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000
8	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000
9	$19,000,000	$4,900,000	$8,600,000	$30,000,000	$63,000,000
10	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000
11	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000
12	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000
13	$19,000,000	$4,900,000	$8,600,000	$30,000,000	$63,000,000
14	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000
15	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000
16	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000
17	$19,000,000	$4,900,000	$8,600,000	$30,000,000	$63,000,000
18	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000
19	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000
20	$850,000	$4,900,000	$8,600,000	$30,000,000	$45,000,000

Notes: Actual numbers may be off due to rounding

Table 117. Cash flow sheet for base design with mesophase pitch recovery and integrated soybean oil processing.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR	Present Value @ DCFROR
-1	$-	$-	$-	$-	$-	$-	$-	($72,000)	($72,000)	($80,000)	($180,000)
0	$-	$-	$-	$-	$-	$-	$-	($110,000)	($110,000)	($110,000)	($110,000)
1	$1,600,000	$860,000	$45,000	$710,000	($22,000)	$690,000	($290,000)		$430,000	$380,000	$170,000
2	$1,600,000	$860,000	$45,000	$710,000	($19,000)	$690,000	($290,000)		$430,000	$340,000	$70,000
3	$1,600,000	$860,000	$45,000	$710,000	($17,000)	$700,000	($290,000)		$430,000	$300,000	$28,000
4	$1,600,000	$860,000	$45,000	$710,000	($15,000)	$700,000	($290,000)		$420,000	$270,000	$11,000
5	$1,600,000	$860,000	$63,000	$700,000	($13,000)	$680,000	($280,000)		$410,000	$230,000	$4,500
6	$1,600,000	$860,000	$45,000	$710,000	($12,000)	$700,000	($290,000)		$420,000	$210,000	$1,800
7	$1,600,000	$860,000	$45,000	$710,000	($10,000)	$700,000	($290,000)		$420,000	$190,000	$750
8	$1,600,000	$860,000	$45,000	$710,000	($9,000)	$700,000	($290,000)		$420,000	$170,000	$300
9	$1,600,000	$860,000	$63,000	$700,000	($7,900)	$690,000	($280,000)		$410,000	$150,000	$120
10	$1,600,000	$860,000	$45,000	$710,000	($7,400)	$710,000	($290,000)		$420,000	$140,000	$49
11	$1,600,000	$860,000	$45,000	$710,000	($7,400)	$710,000	($290,000)		$420,000	$120,000	$20
12	$1,600,000	$860,000	$45,000	$710,000	($7,400)	$710,000	($290,000)		$420,000	$110,000	$8
13	$1,600,000	$860,000	$63,000	$700,000	($7,400)	$690,000	($280,000)		$410,000	$94,000	$3
14	$1,600,000	$860,000	$45,000	$710,000	($7,400)	$710,000	($290,000)		$420,000	$86,000	$1
15	$1,600,000	$860,000	$45,000	$710,000	($7,400)	$710,000	($290,000)		$420,000	$77,000	$1
16	$1,600,000	$860,000	$45,000	$710,000	($7,400)	$710,000	($290,000)		$420,000	$69,000	$0
17	$1,600,000	$860,000	$63,000	$700,000	($7,400)	$690,000	($280,000)		$410,000	$60,000	$0
18	$1,600,000	$860,000	$45,000	$710,000		$710,000	($300,000)		$420,000	$54,000	$0
19	$1,600,000	$860,000	$45,000	$710,000		$710,000	($300,000)		$420,000	$49,000	$0
20	$1,600,000	$860,000	$45,000	$710,000		$710,000	($300,000)	$22,000	$440,000	$46,000	$0
									NPV@HR	$3,000,000	$0
									DCFROR	147%	
									HR	12%	

Notes: Dollar values are in thousands

Actual numbers may be off due to rounding

Numbers in parenthesis represent negative numbers

Table 118. Cash flow sheet for mesophase pitch recovery and integrated soybean oil processing with a soybean price of $0.60/kg.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR
-1	$-	$-	$-	$-	$-	$-	$-	($72,000)	($72,000)	($80,000)
0	$-	$-	$-	$-	$-	$-	$-	($110,000)	($110,000)	($110,000)
1	$1,600,000	$1,500,000	$45,000	$38,000	($22,000)	$16,000	($6,700)		$31,000	$28,000
2	$1,600,000	$1,500,000	$45,000	$38,000	($19,000)	$19,000	($7,700)		$30,000	$24,000
3	$1,600,000	$1,500,000	$45,000	$38,000	($17,000)	$21,000	($8,600)		$29,000	$21,000
4	$1,600,000	$1,500,000	$45,000	$38,000	($15,000)	$23,000	($9,500)		$28,000	$18,000
5	$1,600,000	$1,500,000	$63,000	$20,000	($13,000)	$6,700	($2,800)		$17,000	$9,700
6	$1,600,000	$1,500,000	$45,000	$38,000	($12,000)	$26,000	($11,000)		$27,000	$14,000
7	$1,600,000	$1,500,000	$45,000	$38,000	($10,000)	$27,000	($11,000)		$26,000	$12,000
8	$1,600,000	$1,500,000	$45,000	$38,000	($9,000)	$29,000	($12,000)		$26,000	$10,000
9	$1,600,000	$1,500,000	$63,000	$20,000	($7,900)	$12,000	($4,900)		$15,000	$5,400
10	$1,600,000	$1,500,000	$45,000	$38,000	($7,400)	$30,000	($13,000)		$25,000	$8,100
11	$1,600,000	$1,500,000	$45,000	$38,000	($7,400)	$30,000	($13,000)		$25,000	$7,200
12	$1,600,000	$1,500,000	$45,000	$38,000	($7,400)	$30,000	($13,000)		$25,000	$6,500
13	$1,600,000	$1,500,000	$63,000	$20,000	($7,400)	$12,000	($5,100)		$15,000	$3,400
14	$1,600,000	$1,500,000	$45,000	$38,000	($7,400)	$30,000	($13,000)		$25,000	$5,200
15	$1,600,000	$1,500,000	$45,000	$38,000	($7,400)	$30,000	($13,000)		$25,000	$4,600
16	$1,600,000	$1,500,000	$45,000	$38,000	($7,400)	$30,000	($13,000)		$25,000	$4,100
17	$1,600,000	$1,500,000	$63,000	$20,000	($7,400)	$12,000	($5,100)		$15,000	$2,100
18	$1,600,000	$1,500,000	$45,000	$38,000		$38,000	($16,000)		$22,000	$2,900
19	$1,600,000	$1,500,000	$45,000	$38,000		$38,000	($16,000)		$22,000	$2,600
20	$1,600,000	$1,500,000	$45,000	$38,000		$38,000	($16,000)	$22,000	$44,000	$4,500

NPV@HR	$0
DCFROR	12%
HR	12%

Notes: Actual numbers may be off due to rounding

Dollar values are in thousands

Numbers in parenthesis represent negative numbers

Table 119. Cash flow sheet for mesophase pitch recovery and integrated soybean processing with a soybean meal price of $0.13/kg.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR
-1	$-	$-	$-	$-	$-	$-	$-	($72,000)	($72,000)	($80,000)
0	$-	$-	$-	$-	$-	$-	$-	($110,000)	($110,000)	($110,000)
1	$940,000	$860,000	$45,000	$38,000	($22,000)	$16,000	($6,700)		$31,000	$28,000
2	$940,000	$860,000	$45,000	$38,000	($19,000)	$19,000	($7,700)		$30,000	$24,000
3	$940,000	$860,000	$45,000	$38,000	($17,000)	$21,000	($8,600)		$29,000	$21,000
4	$940,000	$860,000	$45,000	$38,000	($15,000)	$23,000	($9,500)		$28,000	$18,000
5	$940,000	$860,000	$63,000	$20,000	($13,000)	$6,700	($2,800)		$17,000	$9,700
6	$940,000	$860,000	$45,000	$38,000	($12,000)	$26,000	($11,000)		$27,000	$14,000
7	$940,000	$860,000	$45,000	$38,000	($10,000)	$27,000	($11,000)		$26,000	$12,000
8	$940,000	$860,000	$45,000	$38,000	($9,000)	$29,000	($12,000)		$26,000	$10,000
9	$940,000	$860,000	$63,000	$20,000	($7,900)	$12,000	($4,900)		$15,000	$5,400
10	$940,000	$860,000	$45,000	$38,000	($7,400)	$30,000	($13,000)		$25,000	$8,100
11	$940,000	$860,000	$45,000	$38,000	($7,400)	$30,000	($13,000)		$25,000	$7,200
12	$940,000	$860,000	$45,000	$38,000	($7,400)	$30,000	($13,000)		$25,000	$6,500
13	$940,000	$860,000	$63,000	$20,000	($7,400)	$12,000	($5,100)		$15,000	$3,400
14	$940,000	$860,000	$45,000	$38,000	($7,400)	$30,000	($13,000)		$25,000	$5,200
15	$940,000	$860,000	$45,000	$38,000	($7,400)	$30,000	($13,000)		$25,000	$4,600
16	$940,000	$860,000	$45,000	$38,000	($7,400)	$30,000	($13,000)		$25,000	$4,100
17	$940,000	$860,000	$63,000	$20,000	($7,400)	$12,000	($5,100)		$15,000	$2,100
18	$940,000	$860,000	$45,000	$38,000		$38,000	($16,000)		$22,000	$2,900
19	$940,000	$860,000	$45,000	$38,000		$38,000	($16,000)		$22,000	$2,600
20	$940,000	$860,000	$45,000	$38,000		$38,000	($16,000)	$22,000	$44,000	$4,500
									NPV@HR	$0
									DCFROR	12%
									HR	12%

Notes: Actual numbers may be off due to rounding

Dollar values are in thousands

Numbers in parenthesis represent negative numbers

VI.B.4. Fatty Acid Recovery and Heavy end Processing with Integrated Soybean plant

The following sections provide an economic analysis surrounding a biorefinery design that follows the fatty acid recovery design and processing of the heavy ends integrated with the soybean oil processing plant. This design was not fully presented in this thesis, but was mentioned in Section VI.A. This design follows the same design presented in Chapter IV, with the only difference being the addition of the heavy end processing section to process the vacuum tars into the saleable byproduct of mesophase pitch.

VI.B.4.i. Broad Cost Estimate

The capital cost summary for the fatty acid recovery design and heavy end processing integrated with a soybean process plant is shown in Table 120. This table shows the total capital investment needed to complete the project, and was developed as described in Chapter II. The FCI was found to be \$150 million, and the TCI was estimated to be \$180 million ± 40%.

VI.B.4.ii. Raw Material and Manufacturing Cost Estimate

The raw material cost is based on purchasing raw soybeans off the open market for \$0.33/kg [60]. The total raw material cost is \$860 million per year.

The total manufacturing cost for the fatty acid recovery design and heavy end processing integrated with the soybean oil processing plant is \$47 million per year, and \$49 million per year on years the decarboxylate catalyst beds need to be replaced. The manufacturing cost includes chemicals and catalysts costs, operating labor costs, maintenance costs, and utility costs. Table 121 shows the overall yearly operating expense summary for the fatty acid recovery design and heavy end processing integrated with the soybean oil processing design. The plant has an operating factor of 95%. Intermediate results can be found in Appendix C, and communication records can be found in Appendix G.

The catalyst used for the decarboxylation reactors in the fatty acid recovery design was a Ni catalyst. The initial charge for the catalyst (shown on the broad cost estimate) covers the total amount of catalyst needed (62 m^3) for a price of \$2.2 million. This amount is charged every four years in order to recharge the catalyst. It was assumed there was a 4% yearly depletion of the catalyst that needed to be replaced for the in between years. This results in a cost of \$86,000 for those years. A quote from Johnson Matthey Catalysts was used for pricing (\$28/m3).

The chemical required for the fatty acid recovery biorefinery needed for the extraction of the fatty acids from the crackate is 25 wt% trimethylamine (TMA). The initial charge for the chemical (shown on the broad cost estimate) covers the total amount of solvent needed for the extraction process (14,000 kg) for a price of \$500,000. It was assumed there was a 17% yearly depletion that needed to be replaced. This resulted in a yearly cost of \$86,000. A quote from Penta International Corporation was used for pricing (\$7.50/kg).

The chemicals needed for the soybean oil processing plant include mineral oil and hexane. The initial charge for the chemical (shown on the broad cost estimate) covers the total amount of solvents needed for the soybean oil extraction process (260,000 kg hexane and 140 kg of mineral oil) for a total price of \$99,000. It was assumed there was a 17% yearly depletion that needed to be replaced. This resulted in a yearly cost of

$55,000. Prices for the solvents were taken from "Soybean Oil Extraction Using Commercial Hexane" [56].

The fatty acid recovery design with heavy end processing and integrated soybean oil processing consists of an equivalent of 70 major unit operations, which equates to 86 new operators to cover continuous operation, as described in Chapter II. An average operator salary of $62,800 was used, and taking into account an additional 15% for supervision, the yearly operating expense equates out to $6,200,000 per year [53]. The maintenance costs were found to be $9.1 million per year.

The utility costs is $31,000,000 per year. This value includes the boiler feed water, cooling water, electricity, refrigeration, process water, credit for remaining syngas and medium and high pressure steam. The steam was required for the soybean oil processing plant. The prices for all the utilities, except the electricity, were priced based off of Turton [54] heuristics. The electricity values were found from typical ND and MN values [55].

VI.B.2.iii. Revenues

Revenue for the fatty acid recovery design and heavy end processing integrated with the soybean oil processing comes from the sales of jet fuel, diesel fuel no. 2, petroleum naphtha, butane, vacuum bottoms, and C2-C11 fatty acids, soybean meal, and pelleted hulls. Shipping costs were not considered when calculating the amount of revenues generated.

The transportation fuels, jet fuel, diesel fuel no. 2, and petroleum naphtha, produce a revenue of $160 million/year. This value was based on the production of 79,000 liquid m3/year of petroleum naphtha that can be sold for $0.36/L, jet fuel at a rate of $190,000 liquid m3/year which is sold for $0.37/L, and diesel fuel no. 2 produced at 260,000 liquid m3/year and sold at $0.37/L. The remaining by products produce a revenue of $1.7 billion/year. Of this $1.7 billion, $930 million is from the sale of soybean meal, and $510 million is from the sale of mesophase pitch. The total annual revenue for the fatty acid design and heavy end processing integrated with the soybean oil processing plant is $1.9 billion/year.

VI.B.2.iv. Overall Profitability

The cash flow sheet for the fatty acid recovery design and heavy end processing integrated with the soybean oil processing is shown in Table 122. The process has a NPV@12% of $4.1 billion ± 40%. The project produces a gross income of $970 million per year, and has a DCFROR value of 180%. The positive NPV@12% value and a DCFROR value greater than 12% show that the investment is profitable over the project lifecycle.

VI.B.2.v. Break Even Point

Although a significant investment, with the current design and prices of products and raw materials the process recovers the initial investment in the first year of operation. In order for the process to break even over the 20 year lifecycle, the price of soybeans would have to rise to a price of $0.69/kg ($18.80/bushel), which would be an all time high for soybean prices. The cash flow sheet based on a soybean price of $0.69/kg can be seen in Table 123.

The saleable byproduct of soybean meal is not needed for the process to be profitable. It could drop to the price of $0/kg, and the process would still produce an NPV@12% over 20 years of $25 million ± 40%.

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing.

				Purchased Equipment Cost						
Equipment	**Equipment Description**	**Number**	**Capacity/Size Specs**	**Basis Date Year 2004**	**Target Year (2016)**	**Material Factor, Fm**	**Pressure or other Factors, Fp**	**Base bare module factor, Fbm**	**Base bare module cost, Cbm**	**Total**
C-101 A/B	Mesophase Pitch Crusher	2	Capacity : 100 kg/min Power: 1.3 kW MOC: Carbon Steel	$10,000	$13,000	1	1	2.1	$28,000	$56,000
D-601	Flash 1	1	Height: 5.8 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$17,500	$24,000	2.5	1	7	$160,000	$160,000
D-602	Flash 2	1	Height: 5.8 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$17,500	$24,000	2.5	1	7	$160,000	$160,000
D-603	Flash 3	1	Height: 2 m Inside Diameter: 1.2 m Vertical Orientation MOC: Carbon Steel	$6,500	$8,700	1	2	6	$52,000	$52,000
D-604	Acetic Acid Separator 1	1	Height: 1.8 m Inside Diameter: 0.5 m Vertical Orientation MOC: Stainless Steel Clad	$3,500	$4,700	2.5	1.5	7	$33,000	$33,000
D-605	Acetic Acid Separator 2	1	Height: 3.4 m Inside Diameter: 0.8 m Vertical Orientation MOC: Stainless Steel Clad	$10,000	$13,000	2.5	1	4	$54,000	$54,000
D-606	Flash 4	1	Height: 2.8 m Inside Diameter: 0.8 m Vertical Orientation MOC: Carbon Steel	$9,000	$12,000	1	1	4	$48,000	$48,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-607	Flash 5	1	Height: 2.8 m Inside Diameter: 0.8 m Vertical Orientation MOC: Carbon Steel	$9,000	$12,000	1	1.5	5	$60,000	$60,000
D-701	Atmospheric Column	1	Height: 8.2 m Diameter: 2.1 m Trays: 7 Feed: Tray 5 MOC: Carbon Steel	$30,000	$40,000	1	1	4	$160,000	$160,000
D-701 Trays	Atmospheric Column Trays	7	Diameter: 2.1 m MOC: Stainless Steel	From Quote	$2,300	1	1	1.2	$2,800	$20,000
D-702	Vacuum Column	1	Height: 21.8 m Diameter: 4.4 m Trays: 20 Feed: Tray 10 MOC: Carbon Steel	125000	$170,000	1	1	4	$670,000	$670,000
D-702 Trays	Vacuum Column Trays	20	Diameter: 4.4 m MOC: Stainless Steel	From Quote	$3,600	1	1	1.2	$4,300	$86,000
D-703	Water Removal Column	1	Height: 18.8 m Diameter: 2.2 m Trays: 19 Feed: Tray 12 MOC: Stainless Steel Clad	65000	$87,000	2.5	1	7	$610,000	$610,000
D-703 Trays	Water Removal Column Trays	19	Diameter: 2.2 m MOC: Stainless Steel	From Quote	$2,400	1	1	1.2	$2,900	$54,000
D-704	C2-C4 Split Column	1	Height: 19 m Diameter: 1.6 m Trays: 20 Feed: Tray 16 MOC: Stainless Steel Clad	50000	$67,000	2.5	1	7	$470,000	$470,000
D-704 Trays	C2-C4 Split Column Trays	20	Diameter: 1.6 m MOC: Stainless Steel	From Quote	$1,900	1	1	1.2	$2,300	$46,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-705	Acetic Acid Column	1	Height: 20.7 m Diameter: 1.5 m Trays: 22 Feed: Tray 12 MOC: Stainless Steel Clad	50000	$67,000	2.5	1	7	$470,000	$470,000
D-705 Trays	Acetic Acid Column Trays	22	Diameter: 1.5 m MOC: Stainless Steel	From Quote	$1,900	1	1	1.2	$2,300	$50,000
D-706	C6-C7 Split Column	1	Height: 31.5 m Diameter: 1.1 m Trays: 35 Feed: Tray 15 MOC: Stainless Steel Clad	70000	$94,000	2.5	1	7	$660,000	$660,000
D-706 Trays	C6-C7 Split Column Trays	35	Diameter: 1.1 m MOC: Stainless Steel	From Quote	$1,500	1	1	1.2	$1,800	$65,000
D-707	C4-C5 Split Column	1	Height: 28.3 m Diameter: 0.4 m Trays: 32 Feed: Tray 12 MOC: Stainless Steel Clad	70000	$94,000	2.5	1	7	$660,000	$660,000
D-707 Trays	C4-C5 Split Column Trays	32	Diameter: 0.4 m MOC: Stainless Steel	From Quote	$930	1	1	1.2	$1,100	$36,000
D-708	C3-C4 Product Column	1	Height: 24.7 m Diameter: 0.3 m Trays: 28 Feed: Tray 15 MOC: Stainless Steel Clad	35000	$47,000	2.5	1	7	$330,000	$330,000
D-708 Trays	C3-C4 Product Column Trays	28	Diameter: 0.3 m MOC: Stainless Steel	From Quote	$730	1	1	1.2	$870	$24,000
D-709	C5-C6 Product Column	1	Height: 26.7 m Diameter: 0.6 m Trays: 30 Feed: Tray 15 MOC: Stainless Steel Clad	35000	$47,000	2.5	1	7	$330,000	$330,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-709 Trays	C5-C6 Product Column Trays	30	Diameter: 0.6 m MOC: Stainless Steel	From Quote	$1,100	1	1	1.2	$1,300	$40,000
D-710	C8-C9 Split Column	1	Height: 24.7 m Diameter: 2.1 m Trays: 26 Feed: Tray 15 MOC: Stainless Steel Clad	80000	$110,000	2.5	1	7	$750,000	$750,000
D-710 Trays	C8-C9 Split Column Trays	26	Diameter: 2.1 m MOC: Stainless Steel	From Quote	$2,300	1	1	1.2	$2,800	$72,000
D-711	C7-C8 Product Column	1	Height: 25.7 m Diameter: 1.3 m Trays: 28 Feed: Tray 15 MOC: Stainless Steel Clad	60000	$81,000	2.5	1	7	$560,000	$560,000
D-711 Trays	C7-C8 Product Column Trays	28	Diameter: 1.3 m MOC: Stainless Steel	From Quote	$1,700	1	1	1.2	$2,100	$57,000
D-712	C10-C11 Split Column	1	Height: 30.3 m Diameter: 2.4 m Trays: 32 Feed: Tray 19 MOC: Stainless Steel Clad	150000	$200,000	2.5	1	7	$1,400,000	$1,400,000
D-712 Trays	C10-C11 Split Column Trays	32	Diameter: 2.4 m MOC: Stainless Steel	From Quote	$2,500	1	1	1.2	$3,000	$96,000
D-713	C9-C10 Product Column	1	Height: 29.4 m Diameter: 1.5 m Trays: 32 Feed: Tray 17 MOC: Stainless Steel Clad	90000	$120,000	2.5	1	7	$850,000	$850,000
D-713 Trays	C9-C10 Product Column Trays	32	Diameter: 1.5 m MOC: Stainless Steel	From Quote	$1,900	1	1	1.2	$2,300	$72,000
D-714	C11 Product Column	1	Height: 27.8 m Diameter: 1.7 m Trays: 30 Feed: Tray 17 MOC: Stainless Steel Clad	85000	$110,000	2.5	1	7	$800,000	$800,000

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Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-714 Trays	C11 Product Column Trays	30	Diameter: 1.7 m MOC: Stainless Steel	From Quote	$2,000	1	1	1.2	$2,400	$73,000
D-715	Hexane Splitter Column	1	Height: 7.9 m Diameter: 0.9 m Trays: 8 Feed: Tray 4 MOC: Carbon Steel	20000	$27,000	1	1	4	$110,000	$110,000
D-715 Trays	Hexane Splitter Column Trays	8	Diameter: 0.9 m MOC: Stainless Steel	From Quote	$1,000	1	1	1.2	$1,200	$9,900
D-716	Naphtha Jet Cut Column	1	Height: 27.7 m Diameter: 1.6 m Trays: 30 Feed: Tray 7 MOC: Carbon Steel	100000	$130,000	1	1	4	$540,000	$540,000
D-716 Trays	Naphtha Jet Cut Column Trays	30	Diameter: 1.6 m MOC: Stainless Steel	From Quote	$2,000	1	1	1.2	$2,400	$71,000
D-717	Jet Diesel Cut Column	1	Height: 24.8 m Diameter: 3.0 m Trays: 25 Feed: Tray 13 MOC: Carbon Steel	125000	$170,000	1	1	4	$670,000	$670,000
D-717 Trays	Jet Diesel Cut Column Trays	25	Diameter: 3.0 m MOC: Stainless Steel	From Quote	$2,900	1	1	1.2	$3,400	$86,000
D-718	Diesel Fuel Oil Cut Column	1	Height: 47.9 m Diameter: 4.3 m Trays: 50 Feed: Tray 23 MOC: Carbon Steel	250000	$340,000	1	1	4	$1,300,000	$1,300,000
D-718 Trays	Diesel Fuel Oil Cut Column Trays	50	Diameter: 4.3 m MOC: Stainless Steel	From Quote	$3,600	1	1	1.2	$4,300	$210,000
D-719	Syngas Column	1	Height: 37.1 m Diameter: 0.2 m Trays: 40 Feed: Tray 15 MOC: Carbon Steel	30000	$40,000	1	3	8	$320,000	$320,000

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Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-719 Trays	Syngas Column Trays	40	Diameter: 0.2 m MOC: Stainless Steel	From Quote	$500	1	3	1.2	$1,800	$73,000
D-720	Debutanizer Column	1	Height: 11.2 m Diameter: 0.9 m Trays: 12 Feed: Tray 8 MOC: Carbon Steel	25000	$34,000	1	1.5	5	$170,000	$170,000
D-720 Trays	Debutanizer Column Trays	12	Diameter: 0.9 m MOC: Stainless Steel	From Quote	$1,400	1	2	1.2	$3,300	$39,000
D-801	Atmospheric Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	$2,500	$3,400	1	1	3	$10,000	$10,000
D-802	Vacuum Column Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	$6,000	$8,100	1	1	3	$24,000	$24,000
D-803	Water Removal Column Reflux Drum	1	Length: 5.5 m Inside Diameter: 1.4 m Horizontal Orientation MOC: Stainless Steel Clad	$10,000	$13,000	2.5	1	4	$54,000	$54,000
D-804	C2-C4 Split Column Reflux Drum	1	Length: 2.4 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Stainless Steel Clad	$2,000	$2,700	2.5	1	4	$11,000	$11,000
D-805	Acetic Acid Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$2,500	$3,400	2.5	1	4	$13,000	$13,000
D-806	C6-C7 Split Column Reflux Drum	1	Length: 2.4 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Stainless Steel Clad	$2,000	$2,700	2.5	1	4	$11,000	$11,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-807	C4-C5 Split Column Reflux Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Stainless Steel Clad	$1,000	$1,300	2.5	1	4	$5,400	$5,400
D-808	C3-C4 Product Column Reflux Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Stainless Steel Clad	$1,000	$1,300	2.5	1	4	$5,400	$5,400
D-809	C5-C6 Product Column Reflux Drum	1	Length: 1.8 m Inside Diameter: 0.5 m Horizontal Orientation MOC: Stainless Steel Clad	$1,500	$2,000	2.5	1	4	$8,100	$8,100
D-810	C8-C9 Split Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$2,500	$3,400	2.5	1	4	$13,000	$13,000
D-811	C7-C8 Product Column Reflux Drum	1	Length: 2.4 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Stainless Steel Clad	$2,000	$2,700	2.5	1	4	$11,000	$11,000
D-812	C10-C11 Split Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$2,500	$3,400	2.5	1	4	$13,000	$13,000
D-813	C9-C10 Product Column Reflux Drum	1	Length: 2.4 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Stainless Steel Clad	$2,000	$2,700	2.5	1	4	$11,000	$11,000
D-814	C11 Product Column Reflux Drum	1	Length: 2.4 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Stainless Steel Clad	$2,000	$2,700	2.5	1	4	$11,000	$11,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-815	Hexane Splitter Column Reflux Drum	1	Length: 1.8 m Inside Diameter: 0.5 m Horizontal Orientation MOC: Carbon Steel	$1,500	$2,000	1	1	3	$6,000	$6,000
D-816	Naphtha Jet Cut Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	$2,500	$3,400	1	1	3	$10,000	$10,000
D-817	Jet Diesel Cut Column Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	$6,000	$8,100	1	1	3	$24,000	$24,000
D-818	Diesel Fuel Oil Cut Column Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	$6,000	$8,100	1	1	3	$24,000	$24,000
D-819	Syngas Column Reflux Drum	1	Length: 3.6 m Inside Diameter: 0.9 m Horizontal Orientation MOC: Carbon Steel	$4,000	$5,400	1	3	6	$32,000	$32,000
D-820	Debutanizer Column Reflux Drum	1	Length: 3.0 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	$2,500	$3,400	1	1.5	4	$13,000	$13,000
D-821	Acetic Acid Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Stainless Steel Clad	$2,500	$3,400	2.5	1	4	$13,000	$13,000
D-822	Naphtha Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Carbon Steel	$2,500	$3,400	1	1.5	4	$13,000	$13,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-901	Fatty Acid Extractor	2	Height: 6.6 m Diameter: 2.2 m Residence Time: 15 min MOC: Stainless Steel Clad	$25,000	$34,000	2.5	1	7	$240,000	$470,000
D-902	Fatty Acid Separator	1	Height: 5.3 m Diameter: 1.4 m MOC: Stainless Steel Clad	$17,500	$24,000	2.5	1	7	$160,000	$160,000
D-1001 A/B	Flash 3 Compressor Knockout Drum	2	Height: 0.1 m Inside Diameter: 0.02 m Horizontal Orientation MOC: Carbon Steel	$1,000	$1,300	1	1	3	$4,000	$8,100
D-1002 A/B	Stage 1 Light End Knock out Drum	2	Height: 3.1 m Inside Diameter: 1.0 m Horizontal Orientation MOC: Carbon Steel	$5,000	$6,700	1	1	3	$20,000	$40,000
D-1003 A/B	Stage 2 Light End Knock out Drum	2	Height: 1.7 m Inside Diameter: 0.6 m Horizontal Orientation MOC: Carbon Steel	$1,750	$2,400	1	1.5	4	$9,400	$19,000
D-1004 A/B	Stage 3 Light End Knock out Drum	2	Height: 0.9 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Carbon Steel	$1,000	$1,300	1	3	6	$8,100	$16,000
E-601 A/B	Atmospheric Column Condenser	2	Surface Area: 930 m2 Heat Duty: 1950 kW MOC (shell/tube): cs/cs	$40,000	$54,000	1	1	3	$160,000	$320,000
E-602 A/B	Vacuum Column Condenser	2	Surface Area: 51 m2 Heat Duty: 3100 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3	$40,000	$81,000
E-603 A/B	Hexane Splitter Condenser	2	Surface Area: 100 m2 Heat Duty: 97 kW MOC (shell/tube): cs/cs	$15,000	$20,000	1	1	3	$60,000	$120,000

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Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-604 A/B	Naphtha Jet Cut Column Condenser	2	Surface Area: 46 m2 Heat Duty: 825 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3	$40,000	$81,000
E-605 A/B	Jet Diesel Cut Column Condenser	2	Surface Area: 52 m2 Heat Duty: 2100 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3	$40,000	$81,000
E-606 A/B	Diesel Fuel Oil Column Condenser	2	Surface Area: 12 m2 Heat Duty: 1770 kW MOC (shell/tube): cs/cs	$5,000	$6,700	1	1	3	$20,000	$40,000
E-607 A/B	Syngas Column Condenser	2	Surface Area: 230 m2 Heat Duty: 390 kW MOC (shell/tube): cs/cs	$25,000	$34,000	1	1.1	3.5	$120,000	$240,000
E-608 A/B	Debutanizer Column Condenser	2	Surface Area: 99 m2 Heat Duty: 830 kW MOC (shell/tube): cs/cs	$15,000	$20,000	1	1.1	3.5	$71,000	$140,000
E-609 A/B	Water Removal Column Condenser	2	Surface Area: 4540 m2 Heat Duty: 53800 kW MOC (shell/tube): cs/ss	$150,000	$200,000	1.7	1	4	$810,000	$1,600,000
E-610 A/B	C2-C4 Split Column Condenser	2	Surface Area: 1380 m2 Heat Duty: 5500 kW MOC (shell/tube): cs/ss	$70,000	$94,000	1.7	1	4	$380,000	$750,000
E-611 A/B	Acetic Acid Column Condenser	2	Surface Area: 290 m2 Heat Duty: 3400 kW MOC (shell/tube): cs/ss	$30,000	$40,000	1.7	1	4	$160,000	$320,000
E-612 A/B	C6-C7 Condenser	2	Surface Area: 18 m2 Heat Duty: 600 kW MOC (shell/tube): cs/ss	$6,000	$8,100	1.7	1	4	$32,000	$64,000
E-613 A/B	C4-C5 Condenser	2	Surface Area: 3 m2 Heat Duty: 50 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000
E-614 A/B	C3-C4 Condenser	2	Surface Area: 3 m2 Heat Duty: 71 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-615 A/B	C5-C6 Condenser	2	Surface Area: 9 m2 Heat Duty: 270 kW MOC (shell/tube): cs/ss	$5,000	$6,700	1.7	1	4	$27,000	$54,000
E-616 A/B	C8-C9 Condenser	2	Surface Area: 43 m2 Heat Duty: 1630 kW MOC (shell/tube): cs/ss	$10,000	$13,000	1.7	1	4	$54,000	$110,000
E-617 A/B	C7-C8 Condenser	2	Surface Area: 22 m2 Heat Duty: 760 kW MOC (shell/tube): cs/ss	$6,500	$8,700	1.7	1	4	$35,000	$70,000
E-618 A/B	C10-C11 Condenser	2	Surface Area: 1 m2 Heat Duty: 66 kW MOC (shell/tube): cs/ss	$2,000	$2,700	1.7	1	4	$11,000	$21,000
E-619 A/B	C9-C10 Condenser	2	Surface Area: 33 m2 Heat Duty: 650 kW MOC (shell/tube): cs/ss	$7,000	$9,400	1.7	1	4	$38,000	$75,000
E-620 A/B	C11 Condenser	2	Surface Area: 18 m2 Heat Duty: 430 kW MOC (shell/tube): cs/ss	$6,500	$8,700	1.7	1	4	$35,000	$70,000
E-701 A/B	Post Cracking Cooler	2	Surface Area: 320 m2 Heat Duty: 14400 kW MOC (shell/tube): cs/ss	$30,000	$40,000	1.7	1.1	4.25	$170,000	$340,000
E-702 A/B	Flash 2 Cooler	2	Surface Area: 170 m2 Heat Duty: 2700 kW MOC (shell/tube): cs/ss	$20,000	$27,000	1.7	1	4	$110,000	$210,000
E-703 A/B	Pre Flash 3 Cooler	2	Surface Area: 60 m2 Heat Duty: 250 kW MOC (shell/tube): cs/cs	$10,250	$14,000	1	1	3	$41,000	$83,000
E-704 A/B	Syngas Cooler	2	Surface Area: 810 m2 Heat Duty: 2400 kW MOC (shell/tube): cs/cs	$60,000	$81,000	1	1.1	3.5	$280,000	$560,000
E-705 A/B	Stage 1 Cooler	2	Surface Area: 37 m2 Heat Duty: 530 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3	$40,000	$81,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-706 A/B	Stage 2 Cooler	2	Surface Area: 40 m2 Heat Duty: 640 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1.1	3.5	$47,000	$94,000
E-707 A/B	Debutanizer Cooler	2	Surface Area: 12 m2 Heat Duty: 250 kW MOC (shell/tube): cs/cs	$6,000	$8,100	1	1.1	3.5	$28,000	$56,000
E-708 A/B	C6-C7 Cooler	2	Surface Area: 3 m2 Heat Duty: 58 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000
E-709 A/B	C4-C5 Cooler	2	Surface Area: 3 m2 Heat Duty: 50 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000
E-710 A/B	C8-C9 Cooler	2	Surface Area: 7 m2 Heat Duty: 390 kW MOC (shell/tube): cs/ss	$5,000	$6,700	1.7	1	4	$27,000	$54,000
E-711 A/B	C10-C11 Cooler	2	Surface Area: 1 m2 Heat Duty: 66 kW MOC (shell/tube): cs/ss	$2,000	$2,700	1.7	1	4	$11,000	$21,000
E-712 A/B	C11 Cooler	2	Surface Area: 3 m2 Heat Duty: 200 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000
E-713 A/B	Flash 4 Cooler	2	Surface Area: 7 m2 Heat Duty: 560 kW MOC (shell/tube): cs/cs	$5,000	$6,700	1	1	3	$20,000	$40,000
E-714 A/B	Pre Jet Diesel Cut Cooler	2	Surface Area: 3 m2 Heat Duty: 130 kW MOC (shell/tube): cs/cs	$3,000	$4,000	1	1	3	$12,000	$24,000
E-801 A/B	TTCR Preheat	2	Surface Area: 290 m2 Heat Duty: 6300 kW MOC (shell/tube): ss/ss	$30,000	$40,000	3	1.1	6	$240,000	$480,000
E-802 A/B	Atmospheric Column Preheat	2	Surface Area: 35 m2 Heat Duty: 2820 kW MOC (shell/tube): cs/ss	$9,500	$13,000	1.7	1	4	$51,000	$100,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-803 A/B	C3-C4 Heater	2	Surface Area: 1 m2 Heat Duty: 8 kW MOC (shell/tube): cs/ss	$2,000	$2,700	1.7	1	4	$11,000	$21,000
E-804 A/B	Fatty Acid Decarbox Heater	2	Surface Area: 6 m2 Heat Duty: 200 kW MOC (shell/tube): ss/ss	$4,000	$5,400	3	1.1	6	$32,000	$64,000
E-901 A/B	Atmospheric Reboiler	2	Surface Area: 140 m2 Heat Duty: 6800 kW MOC (shell/tube): cs/ss	$18,000	$24,000	1.7	1	4	$97,000	$190,000
E-902 A/B	Vacuum Column Reboiler	2	Surface Area: 140 m2 Heat Duty: 1910 kW MOC (shell/tube): cs/ss	$18,000	$24,000	1.7	1	4	$97,000	$190,000
E-903 A/B	Jet Diesel Cut Reboiler	2	Surface Area: 120 m2 Heat Duty: 3650 kW MOC (shell/tube): cs/ss	$12,000	$16,000	1.7	1	4	$64,000	$130,000
E-904 A/B	Hexane Splitter Column	2	Surface Area: 24 m2 Heat Duty: 1100 kW MOC (shell/tube): cs/ss	$6,500	$8,700	1.7	1	4	$35,000	$70,000
E-905 A/B	Naphtha Jet Reboiler	2	Surface Area: 42 m2 Heat Duty: 1140 kW MOC (shell/tube): cs/ss	$10,000	$13,000	1.7	1	4	$54,000	$110,000
E-906 A/B	Diesel Fuel Oil Cut Reboiler	2	Surface Area: 160 m2 Heat Duty: 2200 kW MOC (shell/tube): cs/ss	$20,000	$27,000	1.7	1	4	$110,000	$210,000
E-907 A/B	Syngas Column Reboiler	2	Surface Area: 14 m2 Heat Duty: 730 kW MOC (shell/tube): cs/ss	$6,000	$8,100	1.7	1.1	4.25	$34,000	$69,000
E-908 A/B	Debutanizer Reboiler	2	Surface Area: 8 m2 Heat Duty: 800 kW MOC (shell/tube): cs/ss	$5,000	$6,700	1.7	1.1	4.25	$29,000	$57,000
E-909 A/B	Water Removal Reboiler	2	Surface Area: 740 m2 Heat Duty: 5600 kW MOC (shell/tube): ss/ss	$50,000	$67,000	3	1	6	$400,000	$810,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-910 A/B	C2-C4 Column Reboiler	2	Surface Area: 130 m2 Heat Duty: 5800 kW MOC (shell/tube): ss/ss	$17,500	$24,000	3	1	6	$140,000	$280,000
E-911 A/B	Acetic Acid Column Reboiler	2	Surface Area: 110 m2 Heat Duty: 6600 kW MOC (shell/tube): ss/ss	$15,000	$20,000	3	1	6	$120,000	$240,000
E-912 A/B	C6-C7 Reboiler	2	Surface Area: 18 m2 Heat Duty: 1260 kW MOC (shell/tube): ss/ss	$6,000	$8,100	3	1	6	$48,000	$97,000
E-913 A/B	C4-C5 Reboiler	2	Surface Area: 4 m2 Heat Duty: 150 kW MOC (shell/tube): ss/ss	$3,000	$4,000	3	1	6	$24,000	$48,000
E-914 A/B	C3-C4 Reboiler	2	Surface Area: 2 m2 Heat Duty: 71 kW MOC (shell/tube): ss/ss	$2,000	$2,700	3	1	6	$16,000	$32,000
E-915 A/B	C5-C6 Product Reboiler	2	Surface Area: 15 m2 Heat Duty: 280 kW MOC (shell/tube): ss/ss	$6,000	$8,100	3	1	6	$48,000	$97,000
E-916 A/B	C8-C9 Reboiler	2	Surface Area: 26 m2 Heat Duty: 1900 kW MOC (shell/tube): ss/ss	$7,000	$9,400	3	1	6	$56,000	$110,000
E-917 A/B	C7-C8 Reboiler	2	Surface Area: 45 m2 Heat Duty: 760 kW MOC (shell/tube): ss/ss	$9,500	$13,000	3	1	6	$77,000	$150,000
E-918 A/B	C10-C11 Reboiler	2	Surface Area: 23 m2 Heat Duty: 1400 kW MOC (shell/tube): ss/ss	$6,000	$8,100	3	1	6	$48,000	$97,000
E-919 A/B	C9-C10 Reboiler	2	Surface Area: 81 m2 Heat Duty: 650 kW MOC (shell/tube): ss/ss	$12,500	$17,000	3	1	6	$100,000	$200,000
E-920 A/B	C11 Reboiler	2	Surface Area: 8 m2 Heat Duty: 560 kW MOC (shell/tube): ss/ss	$7,000	$9,400	3	1	6	$56,000	$110,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-506 A/B	Pitching Preheat	2	Surface Area: 120 m2 Heat Duty: 2400 kW MOC (shell/tube): ss clad/ss	$13,500	$18,000	3	1.25	7	$130,000	$250,000
E-1001 A/B	Naphtha Cooler	2	Surface Area: 100 m2 Heat Duty: 320 kW MOC (shell/tube): cs/cs	$15,000	$20,000	1	1	3	$60,000	$120,000
E-1002 A/B	Jet Cooler	2	Surface Area: 330 m2 Heat Duty: 1800 kW MOC (shell/tube): cs/cs	$35,000	$47,000	1	1	3	$140,000	$280,000
E-1003 A/B	Diesel Cooler 1	2	Surface Area: 140 m2 Heat Duty: 3600 kW MOC (shell/tube): cs/ss	$ 20,000	$27,000	1.7	1	4	$110,000	$210,000
E-1004 A/B	Diesel Cooler 2	2	Surface Area: 150 m2 Heat Duty: 280 kW MOC (shell/tube): cs/cs	$ 20,000	$27,000	1	1	3	$81,000	$160,000
E-1005 A/B	Fuel Oil Cooler	2	Surface Area: 3 m2 Heat Duty: 42 kW MOC (shell/tube): cs/ss	$ 4,000	$5,400	1.7	1	4	$21,000	$43,000
E-1106 A/B	Fuel Oil Cooler 2	2	Surface Area: 690 m2 Heat Duty: 4400 kW MOC (shell/tube): cs/ss	$50,000	$67,000	1.7	1.1	4.5	$300,000	$600,000
J-101 A/B	Pitch Reactor Product Screw Conveyor	2	Length: 6 m Width: 1.5 m	$12,500	$17,000	1	1	2.4	$40,000	$81,000
J-101 A/B - Motor	Pitch Reactor Product Screw Conveyor Motor	2	Power: 870 W	$300	$400	1	1	2	$810	$1,600
J-102 A/B	Crusher Feed Belt Conveyor	2	Length: 3 m Width: 1.5 m	$10,000	$13,000	1	1	2.4	$32,000	$64,000
J-102 A/B - Motor	Pitch Reactor Product Screw Conveyor Motor	2	Power: 430 W	$250	$340	1	1	2	$670	$1,300
J-103 A/B	Mesophase Pitch Belt Conveyor	2	Length: 150 m Width: 1.5 m	$100,000	$130,000	1	1	2.4	$320,000	$640,000
J-103 A/B - Motor	Pitch Reactor Product Screw Conveyor Motor	2	Power: 16 kW	$1,500	$2,000	1	1	2	$4,000	$8,100

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
G-201 A/B	Flash 2 Compressor	2	Power: 17 kW Number of Stages: 1 MOC: Stainless Steel	From Quote	$18,000	1	1	2.5	$45,000	$91,000
G-202 A/B	Flash 3 Compressor	2	Power: 1 kW Number of Stages: 1 MOC: Carbon Steel	From Quote	$55	1	1	2.5	$140	$280
G-203	Light End Compressor	1	Power: 1500 kW Number of Stages: 3 MOC: Carbon Steel	From Quote	$1,600,000	1	1	2.5	$4,100,000	$4,100,000
L-201 A/B	PreCracking Pump	2	Power: 54 kW Suction Pressure: 110 kPa MOC: Stainless Steel	$17,500	$24,000	1.9	1	5	$120,000	$240,000
L-203 A/B	Post Extractor Pump	2	Power: 1 kW Suction Pressure: 140 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	6	$24,000	$48,000
L-204 A/B	Atmospheric Reflux	2	Power: 2 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	4	$27,000	$54,000
L-205 A/B	Vacuum Reflux	2	Power: 5 kW Suction Pressure: 7 kPa MOC: Carbon Steel	$6,000	$8,100	1.4	1	4	$32,000	$64,000
L-206 A/B	Vacuum Bottoms	2	Power: 1 kW Suction Pressure: 40 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-207 A/B	Naphtha Cut Pump	2	Power: 1 kW Suction Pressure: 130 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-208 A/B	Flash 5 Pump	2	Power: 1 kW Suction Pressure: 102 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-209 A/B	Syngas Column Reflux	2	Power: 5 kW Suction Pressure: 3200 kPa MOC: Carbon Steel	$6,000	$8,100	1.4	1.75	6	$48,000	$97,000
L-210 A/B	Debutanizer Reflux	2	Power: 2 kW Suction Pressure: 790 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	4	$27,000	$54,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-211 A/B	Hexane Splitter Bottoms	2	Power: 1 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-212 A/B	Hexane Splitter Reflux	2	Power: 2 kW Suction Pressure: 90 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	4	$27,000	$54,000
L-213 A/B	Naphtha Reflux	2	Power: 5 kW Suction Pressure: 90 kPa MOC: Carbon Steel	$6,000	$8,100	1.4	1	4	$32,000	$64,000
L-214 A/B	Pre Jet Pump	2	Power: 2 kW Suction Pressure: 102 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	4	$27,000	$54,000
L-215 A/B	Jet Reflux	2	Power: 4 kW Suction Pressure: 68 kPa MOC: Carbon Steel	$5,500	$7,400	1.4	1	4	$30,000	$59,000
L-216 A/B	Jet Bottoms	2	Power: 1 kW Suction Pressure: 110 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-217 A/B	Diesel Reflux	2	Power: 8 kW Suction Pressure: 102 kPa MOC: Carbon Steel	$8,000	$11,000	1.4	1	4	$43,000	$86,000
L-218 A/B	Water Removal Reflux	2	Power: 5 kW Suction Pressure: 14 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-219 A/B	Water Removal Bottoms	2	Power: 1 kW Suction Pressure: 69 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-220 A/B	Solvent Recycle Pump	2	Power: 2 kW Suction Pressure: 69 kPa MOC: Stainless Steel	$5,000	$6,700	1.9	1	5	$34,000	$67,000
L-221 A/B	Acetic Acid Reflux	2	Power: 6 kW Suction Pressure: 69 kPa MOC: Stainless Steel	$7,000	$9,400	1.9	1	5	$47,000	$94,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-222 A/B	C3 Bottoms	2	Power: 1 kW Suction Pressure: 14 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-223 A/B	C3 Reflux	2	Power: 5 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-224 A/B	C6-C7 Reflux	2	Power: 7 kW Suction Pressure: 69 kPa MOC: Stainless Steel	$7,500	$10,000	1.9	1	5	$50,000	$100,000
L-225 A/B	C6-C7 Bottoms	2	Power: 1 kW Suction Pressure: 116 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-226 A/B	C4-C5 Reflux	2	Power: 7 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$7,500	$10,000	1.9	1	5	$50,000	$100,000
L-227 A/B	C4-C5 Bottoms	2	Power: 1 kW Suction Pressure: 55 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-228 A/B	C3-C4 Reflux	2	Power: 6 kW Suction Pressure: 34 kPa MOC: Stainless Steel	$7,000	$9,400	1.9	1	5	$47,000	$94,000
L-229 A/B	C3-C4 Bottoms	2	Power: 1 kW Suction Pressure: 55 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-230 A/B	C5-C6 Bottoms	2	Power: 1 kW Suction Pressure: 82 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-231 A/B	C5-C6 Reflux	2	Power: 6 kW Suction Pressure: 62 kPa MOC: Stainless Steel	$7,000	$9,400	1.9	1	5	$47,000	$94,000
L-232 A/B	C8-C9 Bottoms	2	Power: 1 kW Suction Pressure: 41 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-233 A/B	C8-C9 Reflux	2	Power: 5 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-234 A/B	C7-C8 Bottoms	2	Power: 1 kW Suction Pressure: 34 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-235 A/B	C7-C8 Reflux	2	Power: 5 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-236 A/B	C10-C11 Bottoms	2	Power: 1 kW Suction Pressure: 14 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-237 A/B	C10-C11 Reflux	2	Power: 6 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$7,000	$9,400	1.9	1	5	$47,000	$94,000
L-238 A/B	C9-C10 Reflux	2	Power: 5 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-239 A/B	C9-10 Bottoms	2	Power: 1 kW Suction Pressure: 14 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-240 A/B	C11 Reflux	2	Power: 5 kW Suction Pressure: 4 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-241 A/B	C11 Bottoms	2	Power: 7 kW Suction Pressure: 21 kPa MOC: Stainless Steel	$7,500	$10,000	1.9	1	5	$50,000	$100,000
L-242 A/B	Jet Product	2	Power: 1 kW Suction Pressure: 69 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-243 A/B	Diesel Product	2	Power: 1 kW Suction Pressure: 102 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-244 A/B	C9-C10 Reflux	2	Power: 5 kW Suction Pressure: 7 kPa MOC: Stainless Steel	$6,000	$8,100	1.9	1	5	$40,000	$81,000
L-245 A/B	Post Extractor Pump 2	2	Power: 1 kW Suction Pressure: 102 kPa MOC: Stainless Steel	$3,000	$4,000	1.9	1	5	$20,000	$40,000
L-246 A/B	Atmospheric Top Pump	2	Power: 2 kW Suction Pressure: 96 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	4	$27,000	$54,000
L-247 A/B	Vacuum Top Pump	2	Power: 3 kW Suction Pressure: 7 kPa MOC: Carbon Steel	$4,000	$5,400	1.4	1	4	$21,000	$43,000
L-248 A/B	Naphtha Product	2	Power: 1 kW Suction Pressure: 102 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	4	$16,000	$32,000
L-249 A/B	C2-C4 Split Top	2	Power: 1 kW Suction Pressure: 3 kPa MOC: Stainless Steel	3000	$4,000	1.9	1	5	$20,000	$40,000
L-250 A/B	C4-C5 Split Top	2	Power: 1 kW Suction Pressure: 21 kPa MOC: Stainless Steel	3000	$4,000	1.9	1	5	$20,000	$40,000
L-251 A/B	C3-C4 Product Top	2	Power: 1 kW Suction Pressure: 34 kPa MOC: Stainless Steel	3000	$4,000	1.9	1	5	$20,000	$40,000
L-252 A/B	C5-C6 Product Top	2	Power: 1 kW Suction Pressure: 161 kPa MOC: Stainless Steel	3000	$4,000	1.9	1	5	$20,000	$40,000
L-253 A/B	C8-C9 Split Top	2	Power: 1 kW Suction Pressure: 21 kPa MOC: Stainless Steel	3000	$4,000	1.9	1	5	$20,000	$40,000
L-254 A/B	C7-C8 Product Top	2	Power: 1 kW Suction Pressure: 21 kPa MOC: Stainless Steel	3000	$4,000	1.9	1	5	$20,000	$40,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-255 A/B	C10-C11 Split Top	2	Power: 1 kW Suction Pressure: 7 kPa MOC: Stainless Steel	3000	$4,000	1.9	1	5	$20,000	$40,000
L-256 A/B	C9-C10 Split Top	2	Power: 1 kW Suction Pressure: 7 kPa MOC: Stainless Steel	3000	$4,000	1.9	1	5	$20,000	$40,000
L-257 A/B	C11 Top	2	Power: 2.5 kW Suction Pressure: 7 kPa MOC: Stainless Steel	5500	$7,400	1.9	1	5	$37,000	$74,000
L-258 A/B	Flash 3 Pump	2	Power: 1 kW Suction Pressure: 105 kPa MOC: Carbon Steel	3000	$4,000	1.4	1	4	$16,000	$32,000
L-259 A/B	Pre Jet Pump 2	2	Power: 1 kW Suction Pressure: 104 kPa MOC: Carbon Steel	3000	$4,000	1.4	1	4	$16,000	$32,000
P-201	Refrigeration System	1	Load: 820-890 metric tons Power: 200 Volts	From Quote	$1,800,000	1	1	3.2	$5,900,000	$5,900,000
Q-201	TTCR Boiler	1	Duty: 85,000 kW	From Quote	$2,400,000	1	1	3.2	$7,700,000	$7,700,000
Q-202	High Pressure Steam Boiler	1	Duty: 82,000 kW	From Quote	$2,400,000	1	1	3.2	$7,600,000	$7,600,000
R-201	TTCR	1	Diameter: 6.1 m Length: 12.2 m Tubes: 10300 MOC: cs/inconel	From Quote	$30,000,000	0.7	1	3.2	$21,000,000	$21,000,000
R-202 A/B	Fatty Acid Decarboxylation Reactor	2	Diameter: 1.8 m Length: 11.2 m MOC: Stainless Steel Clad	From Quote	$390,000	1	1	3.2	$390,000	$780,000
R-104 A/B	Pitching Reactor	2	Diameter: 1.2 m Height: 3.6 m MOC: Stainless Steel Clad	360000	$480,000	1	1	3.2	$1,500,000	$3,100,000

(continued)

Table 120. Broad cost estimate for fatty acid recovery and heavy end processing design integrated with soybean processing cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
	Extraction, Solvent Recovery, MOS, and Work Tank Sections	1	Capacity: 7500 MTPD	17850000	$18,000,000	0.9	1	1	$16,000,000	$16,000,000
	Prep and Pelletizing Sections	1	Capacity: 7500 MTPD	10000000	$9,900,000	1	1	1	$9,900,000	$9,900,000

Total Bare Module Cost	**CTBM**	$110,000,000
Contingency and Fees	**CTBM*0.18**	$19,000,000
Total Module Cost	**CTM**	$130,000,000
Auxiliary Facilities	**CTM*0.2**	$25,000,000
Fixed Capital Investment	**FCI**	$150,000,000
Working Capital	**FCI*0.15**	$23,000,000
Chemicals & Catalysts		$2,700,000
Total Capital Investment	**TCI**	$180,000,000

Note: Actual numbers may be off due to rounding

Table 121. Operating expense summary for fatty acid recovery and heavy end processing design integrated with soybean processing.

Year	Chemicals and Catalysts	Operating Labor	Maintenance	Utilities	Yearly Total
1	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000
2	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000
3	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000
4	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000
5	$2,300,000	$6,200,000	$9,100,000	$31,000,000	$49,000,000
6	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000
7	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000
8	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000
9	$2,300,000	$6,200,000	$9,100,000	$31,000,000	$49,000,000
10	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000
11	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000
12	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000
13	$2,300,000	$6,200,000	$9,100,000	$31,000,000	$49,000,000
14	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000
15	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000
16	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000
17	$2,300,000	$6,200,000	$9,100,000	$31,000,000	$49,000,000
18	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000
19	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000
20	$270,000	$6,200,000	$9,100,000	$31,000,000	$47,000,000

Notes: Actual numbers may be off due to rounding

Table 122. Cash flow sheet for fatty acid recovery and heavy end processing design integrated with soybean processing.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR	Present Value @ DCFROR
-1	$-	$-	$-	$-	$-	$-	$-	($76,000)	($76,000)	($85,000)	($210,000)
0	$-	$-	$-	$-	$-	$-	$-	($100,000)	($100,000)	($100,000)	($100,000)
1	$1,900,000	$860,000	$47,000	$970,000	($21,000)	$950,000	($390,000)		$580,000	$520,000	$200,000
2	$1,900,000	$860,000	$47,000	$970,000	($18,000)	$950,000	($390,000)		$580,000	$460,000	$72,000
3	$1,900,000	$860,000	$47,000	$970,000	($16,000)	$960,000	($400,000)		$580,000	$410,000	$25,000
4	$1,900,000	$860,000	$47,000	$970,000	($14,000)	$960,000	($400,000)		$580,000	$370,000	$8,900
5	$1,900,000	$860,000	$49,000	$970,000	($13,000)	$960,000	($400,000)		$570,000	$330,000	$3,100
6	$1,900,000	$860,000	$47,000	$970,000	($11,000)	$960,000	($400,000)		$570,000	$290,000	$1,100
7	$1,900,000	$860,000	$47,000	$970,000	($9,800)	$960,000	($400,000)		$570,000	$260,000	$390
8	$1,900,000	$860,000	$47,000	$970,000	($8,600)	$960,000	($400,000)		$570,000	$230,000	$140
9	$1,900,000	$860,000	$49,000	$970,000	($7,600)	$960,000	($400,000)		$570,000	$210,000	$48
10	$1,900,000	$860,000	$47,000	$970,000	($7,200)	$970,000	($400,000)		$570,000	$180,000	$17
11	$1,900,000	$860,000	$47,000	$970,000	($7,200)	$970,000	($400,000)		$570,000	$160,000	$6
12	$1,900,000	$860,000	$47,000	$970,000	($7,200)	$970,000	($400,000)		$570,000	$150,000	$2
13	$1,900,000	$860,000	$49,000	$970,000	($7,200)	$960,000	($400,000)		$570,000	$130,000	$1
14	$1,900,000	$860,000	$47,000	$970,000	($7,200)	$970,000	($400,000)		$570,000	$120,000	$0
15	$1,900,000	$860,000	$47,000	$970,000	($7,200)	$970,000	($400,000)		$570,000	$100,000	$0
16	$1,900,000	$860,000	$47,000	$970,000	($7,200)	$970,000	($400,000)		$570,000	$94,000	$0
17	$1,900,000	$860,000	$49,000	$970,000	($7,200)	$960,000	($400,000)		$570,000	$83,000	$0
18	$1,900,000	$860,000	$47,000	$970,000		$970,000	($400,000)		$570,000	$74,000	$0
19	$1,900,000	$860,000	$47,000	$970,000		$970,000	($400,000)		$570,000	$66,000	$0
20	$1,900,000	$860,000	$47,000	$970,000		$970,000	($400,000)	$23,000	$590,000	$61,000	$0
									NPV@HR	$4,100,000	$0
									DCFROR	180%	
									HR	12%	

Notes: Actual numbers may be off due to rounding

Dollar values are in thousands

Numbers in parenthesis represent negative numbers

Table 12. Cash flow sheet for fatty acid recovery and heavy end processing design integrated with soybean processing with soybean price of $0.69/kg.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR
-1	$-	$-	$-	$-	$-	$-	$-	($76,000)	($76,000)	($85,000)
0	$-	$-	$-	$-	$-	$-	$-	($100,000)	($100,000)	($100,000)
1	$1,900,000	$1,800,000	$47,000	$34,000	($21,000)	$13,000	($5,400)		$28,000	$25,000
2	$1,900,000	$1,800,000	$47,000	$34,000	($18,000)	$15,000	($6,400)		$27,000	$22,000
3	$1,900,000	$1,800,000	$47,000	$34,000	($16,000)	$18,000	($7,300)		$26,000	$19,000
4	$1,900,000	$1,800,000	$47,000	$34,000	($14,000)	$19,000	($8,000)		$26,000	$16,000
5	$1,900,000	$1,800,000	$49,000	$32,000	($13,000)	$19,000	($7,900)		$24,000	$13,000
6	$1,900,000	$1,800,000	$47,000	$34,000	($11,000)	$23,000	($9,300)		$24,000	$12,000
7	$1,900,000	$1,800,000	$47,000	$34,000	($9,800)	$24,000	($9,900)		$24,000	$11,000
8	$1,900,000	$1,800,000	$47,000	$34,000	($8,600)	$25,000	($10,000)		$23,000	$9,400
9	$1,900,000	$1,800,000	$49,000	$32,000	($7,600)	$24,000	($9,900)		$22,000	$7,800
10	$1,900,000	$1,800,000	$47,000	$34,000	($7,200)	$27,000	($11,000)		$23,000	$7,300
11	$1,900,000	$1,800,000	$47,000	$34,000	($7,200)	$27,000	($11,000)		$23,000	$6,500
12	$1,900,000	$1,800,000	$47,000	$34,000	($7,200)	$27,000	($11,000)		$23,000	$5,800
13	$1,900,000	$1,800,000	$49,000	$32,000	($7,200)	$24,000	($10,000)		$22,000	$4,900
14	$1,900,000	$1,800,000	$47,000	$34,000	($7,200)	$27,000	($11,000)		$23,000	$4,600
15	$1,900,000	$1,800,000	$47,000	$34,000	($7,200)	$27,000	($11,000)		$23,000	$4,200
16	$1,900,000	$1,800,000	$47,000	$34,000	($7,200)	$27,000	($11,000)		$23,000	$3,700
17	$1,900,000	$1,800,000	$49,000	$32,000	($7,200)	$24,000	($10,000)		$22,000	$3,100
18	$1,900,000	$1,800,000	$47,000	$34,000		$34,000	($14,000)		$20,000	$2,600
19	$1,900,000	$1,800,000	$47,000	$34,000		$34,000	($14,000)		$20,000	$2,300
20	$1,900,000	$1,800,000	$47,000	$34,000		$34,000	($14,000)	$23,000	$42,000	$4,400
									NPV@HR	$0
									HR	12%

Notes: Actual numbers may be off due to rounding, Dollar values are in thousands
Numbers in parenthesis represent negative numbers

Chapter VII

HAZARDS ANALYSIS

The major risk surrounding the development of a biorefinery based on the noncatalytic cracking of triglyceride oils is that the primary raw material and principal products are from separate industries. This means that the prices of the products and raw materials are not necessarily linked, so when the price of TAG oils rises the price of transportation fuels may not rise. By contrast, an increase in crude oil prices, the raw material for petroleum transportation fuels, leads to an immediate increase in fuel product prices.

The wholesale price of petroleum grade naphtha, jet fuel, and diesel fuel no. 2 (dotted lines) have been plotted over time against the price of crude oil (solid line) in Figure 9 to show the trend of the economics pertaining to the noncatalytic cracking process. In addition, the wholesale price of crude oil (solid line) has also been plotted against the price of soybean oil (dotted line) on Figure 10 for reference.

What can be seen from Figures 9 and 10 is that the values for fossil fuels and TAG oil tend to correlate, but not as tightly as fuels to crude oil. It is unclear if this is a natural result or a result from recent supply/demand, but it seems that within the coming years the margin between TAG costs and the price of fuels will stay fairly consistent (on a mass basis). What can also be seen is that based on the transportation fuel yields from the biorefineries designed in previous chapters that the profit margin from the noncatalytic cracking process based purely on a TAG-to-fuel process is fairly weak, and the introduction of high value byproducts or integration with a soybean processing facility may be necessary for the process to be economical.

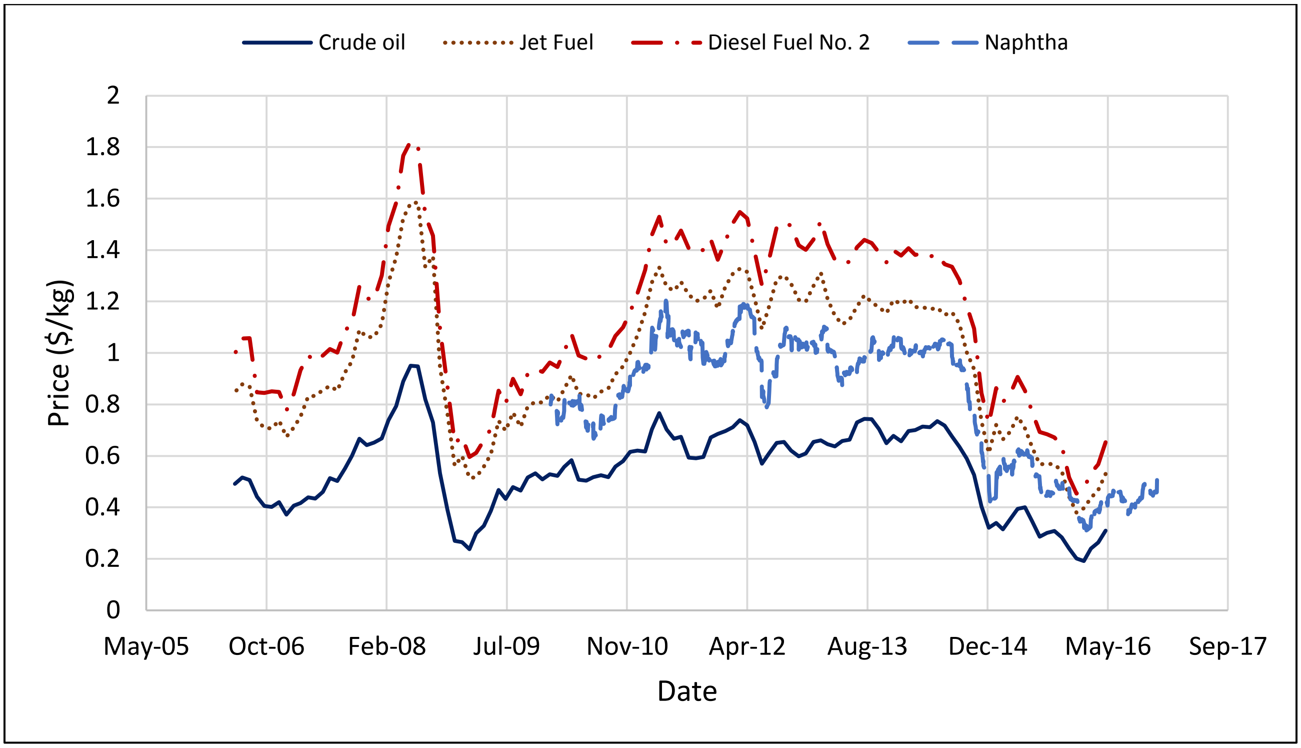


Figure 9. Historical price of fossil fuels and crude oil [22, 24-26].

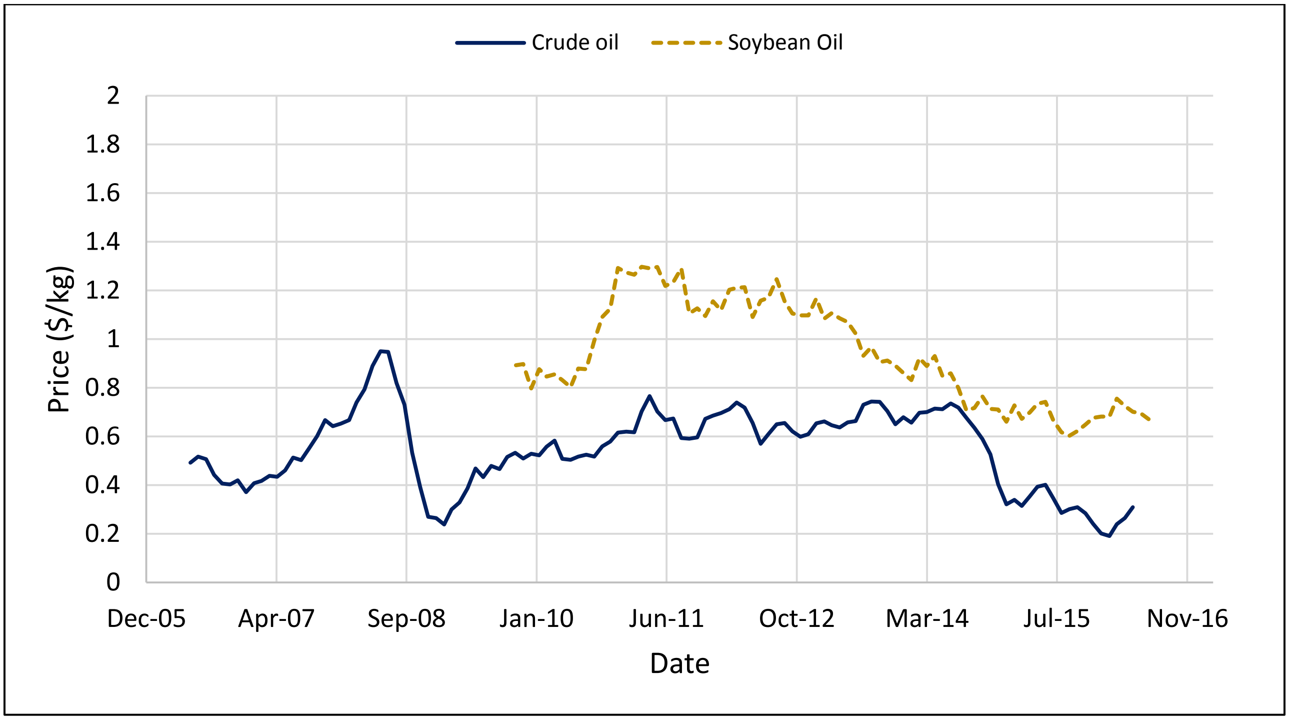


Figure 10. Historical price of soybean oil and crude oil [20, 22].

The following sections review the main hazards for the investment into a biorefinery based on noncatalytic cracking of TAG oils. Section VII.A. reviews the hazards associated with the base design presented in Chapter III. Section VII.B. explains the hazards surrounding the fatty acid recovery design shown in Chapter IV. Section VII.C. describes the hazards of the heavy end processing design displayed in Chapter V. Finally Section VII.D. evaluates the hazards associated with a biorefinery integrated with a soybean oil processing plant that was introduced in Chapter VI.

VII.A. Base Design Hazard Analysis

The main hazard to the investment for the base design of a biorefinery based on noncatalytic cracking is the margin between the raw material price (TAG oil) and the value of the transportation fuel products. Figure 11 plots the gross margin between the transportation fuel products (petroleum naphtha, jet fuel, and diesel fuel no. 2) and the raw material used for the process (soybean oil) over the last 6 years based on the fuel yields in this design (Chapter III). This margin assumes the purchase of food grade soybean oil at wholesale spot market prices and thus represents a near worst case scenario. The 2016 values were the current prices used for the products and raw material presented in Chapter 1, while the 2015-2010 years were the average price of each over the year.

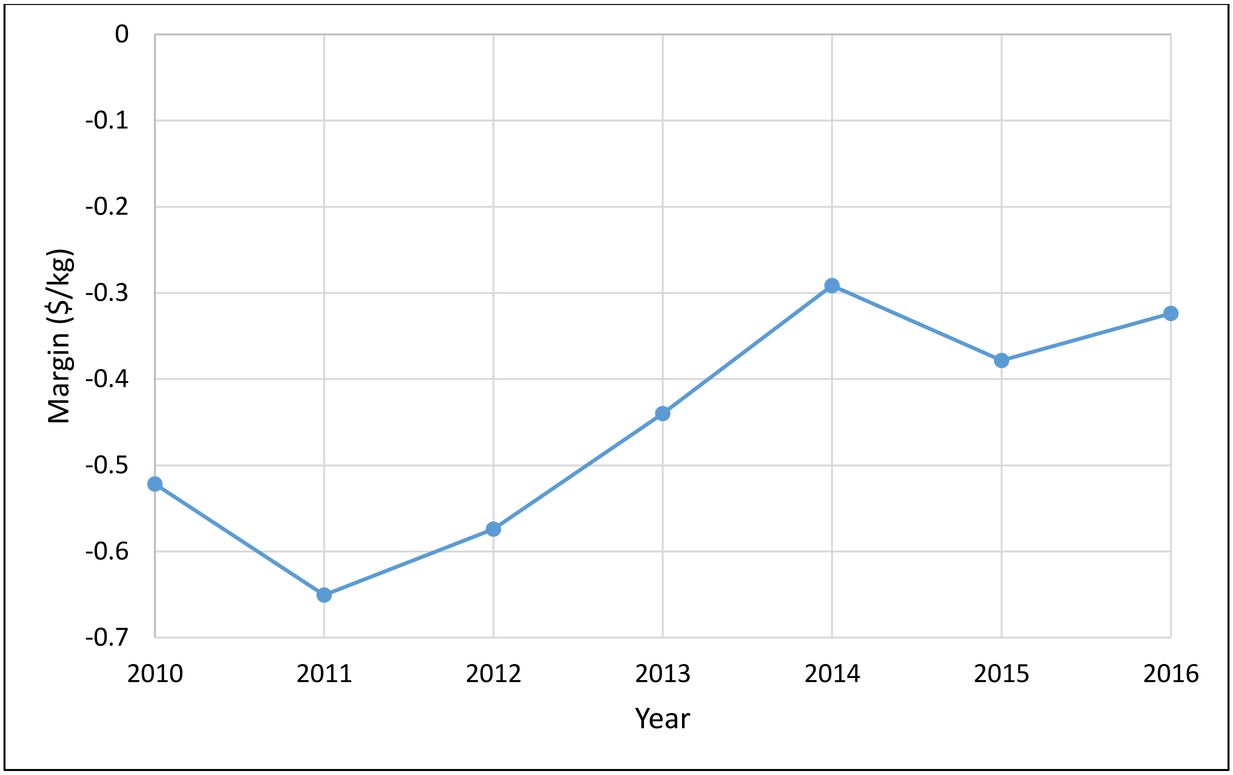


Figure 11. Margin of transportation fuels and soybean oil on a mass basis for base design.

As can be seen from Figure 11, the current prices used for the products and raw materials have a margin at the high end over the last six years. A sensitivity analysis of the margin on the NPV @ 12% is shown in Figure 12. The region of most probably uncertainty for the margin is the high value (from 2014) and low value (from 2011) seen over the last six years. As can be seen from the figure, the margin between the fuel products and raw material would have to fall just above $0.04/kg feed for the base design to break even. This would require a TAG oil price of $0.22/kg (as shown in Chapter III).

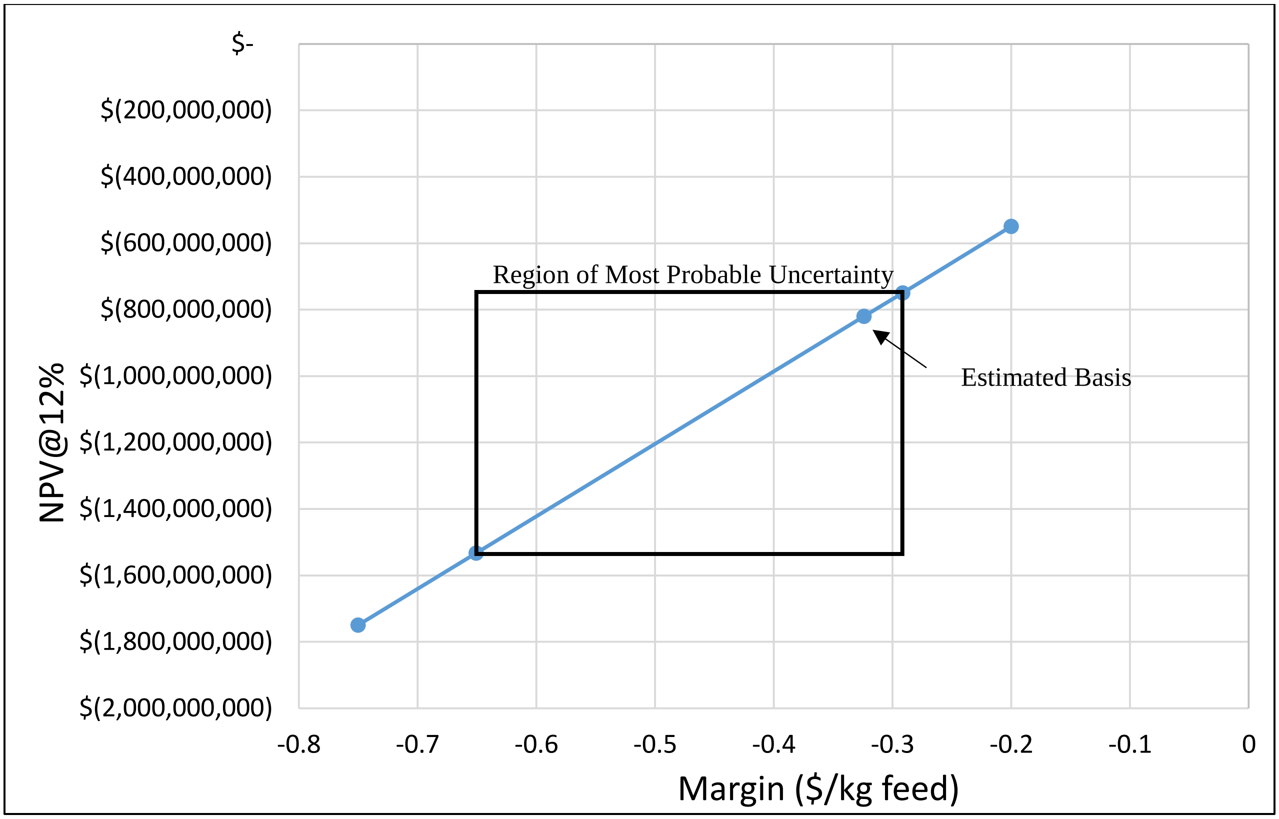


Figure 12. Sensitivity analysis for margin between transportation fuels and soybean oil for base design.

At the current soybean oil price of $0.60/kg the base design is not feasible. Also, the price of soybean oil has not reached a low of $0.22/kg in recent history. Therefore, with the historic prices of transportation fuels it would be infeasible to use the base biorefinery design based on using 3rd party food grade soybean oil. However, using a cheaper oil as the TAG feedstock has the potential to produce a design that is profitable.

The current price for waste cooking oil is roughly $0.30/kg, which is still significantly higher than the breakeven price. The lowest price for waste cooking oil over the last 15 years was $0.11/kg (2005), which would make the base design profitable with current transportation fuel prices [61]. The only problem is that waste cooking oil prices tend to follow a similar trend to biodiesel, which follows closely along with petroleum diesel. This common trend is because biodiesel production from fats and vegetable oils has been increasing over the past decade. Therefore, as the price for crude oil increases, this leads to an increased price in transportation fuels (biodiesel included), which in turn leads to increases in prices of waste cooking oils [61]. This makes determining the economic feasibility using waste cooking oil as a feed stock difficult.

For example, during the 2005-2006 period when waste cooking oils were at a low, the margin between the transportation fuels and waste oil was \$0.17/kg feed (assuming similar transportation fuel yields with this feedstock), which is over the \$0.04/kg feed margin needed for the base design to become profitable over the 20 year lifecycle. On the other hand, in 2013 when waste cooking oils were peaking, the \$0.79/kg sale price of waste oil would result in a margin of \$-0.22/kg feed, falling below the breakeven value.

VII.B. Fatty Acid Recovery Design Hazard Analysis

The main hazard for the fatty acid recovery design is again the margin between the raw material price (TAG oil) and transportation fuel products, as it was for the base design. Figure 13 plots the gross margin between the transportation fuel products (petroleum naphtha, jet fuel, and diesel fuel no. 2) and the raw material used for the process (soybean oil) over the last 6 years based on the fuel yields in this design (Chapter IV). The 2016 values were the current prices used for the products and raw material presented in Chapter 1, while the 2015-2010 years were the average price of each over the year.

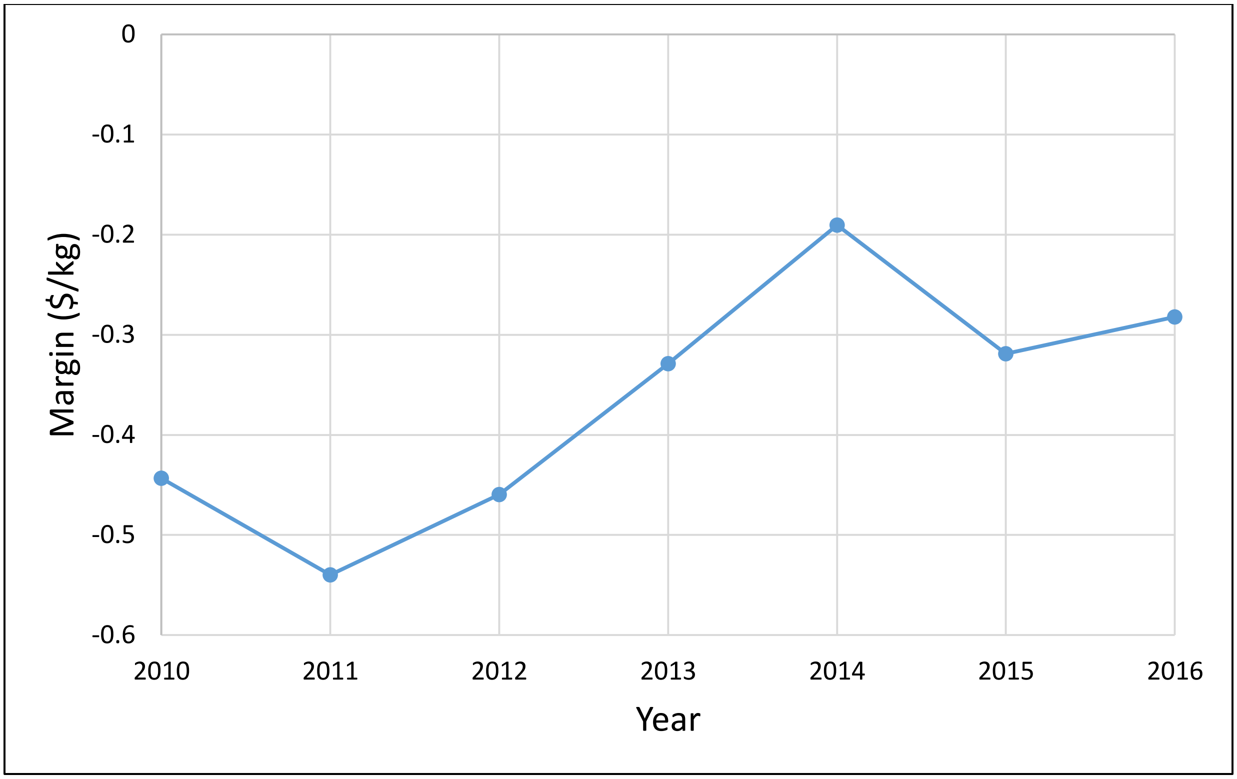


Figure 13. Margin of transportation fuels and soybean oil on a mass basis for fatty acid recovery design.

As stated in the previous section, the current prices of soybean oil and transportation fuels results in the second highest margin seen over the last six years. A sensitivity analysis of the margin on the NPV @ 12% for the fatty acid recovery design is shown in Figure 14. The region of most probably uncertainty for the margin is the high value (from 2014) and low value (from 2011) seen over the last six years. As seen from the figure, if the margin between the transportation fuels and inlet oil were to fall below $-0.43/kg feed for the process, a $0 NPV@12% over 20 years would result. For the current prices of transportation fuels, that would require a TAG oil price of $0.76/kg to only break even over the 20 year life cycle (as shown in Chapter IV).

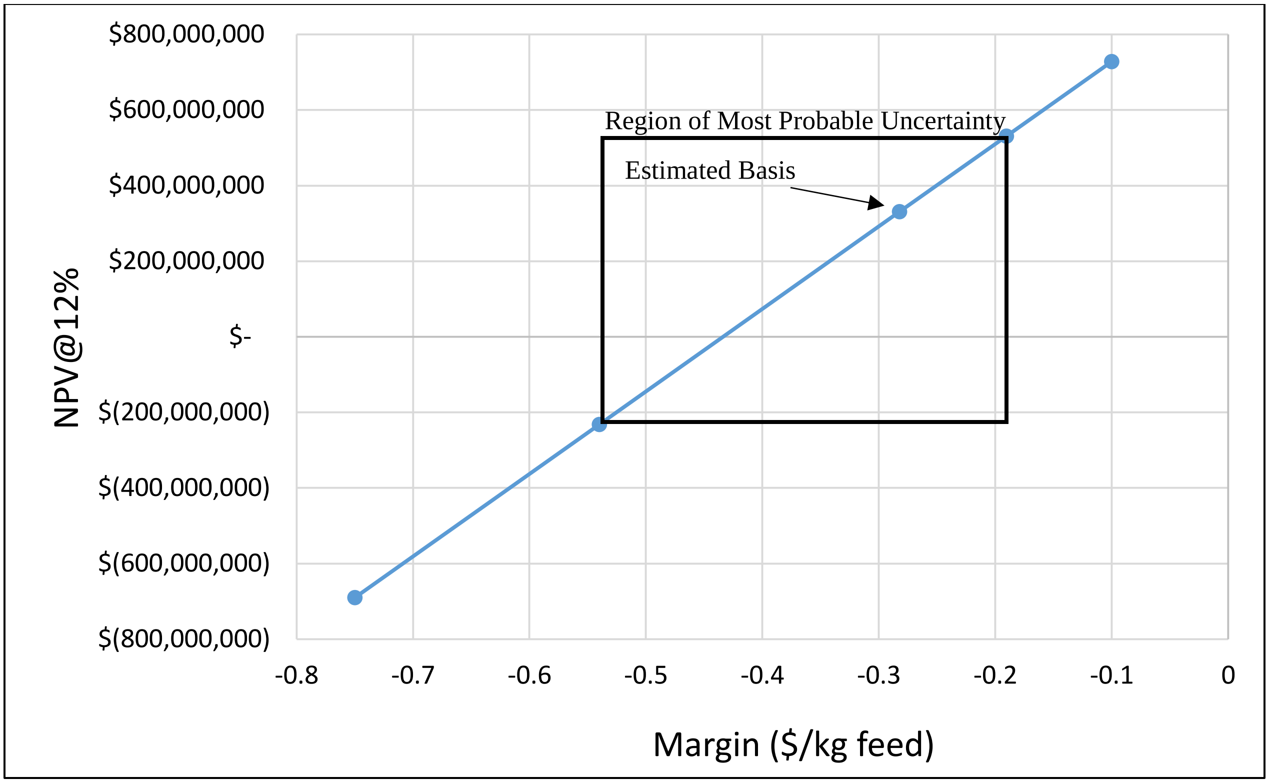


Figure 14. Sensitivity analysis for margin between transportation fuels and soybean oil for fatty acid recovery design.

If the margin between soybean oil and the transportation fuels were to ever drop below $-0.43/kg feed, which last happened in 2010-2012, there would be a good chance that the margin between the fuels and waste cooking oil would be larger than this break even value. Being that the margin between waste cooking oils and transportation fuels in 2013 (during a period of increased waste oil prices) was $-0.11/kg feed, which is still significantly higher than the breakeven margin. This makes the fatty acid recovery alternative economically justifiable even with fluctuating soybean oil prices.

VII.C. Heavy End Processing Hazard Analysis

The main hazards to the investment for the heavy end processing design are the margin between the raw material price (TAG oil) and transportation fuel products, and the price of mesophase pitch. Figure 11, in Section VII.A., plots the margin vs. time based on the fuel yields in this design (Chapter V). As stated above, the current margin between fuel products and soybean oil is relatively high. The sensitivity analysis of the margin on the NPV @ 12% for the heavy end processing design is shown in Figure 15. The region of most probably uncertainty for the margin is the high value (from 2014) and low value (from 2011) seen over the last six years.

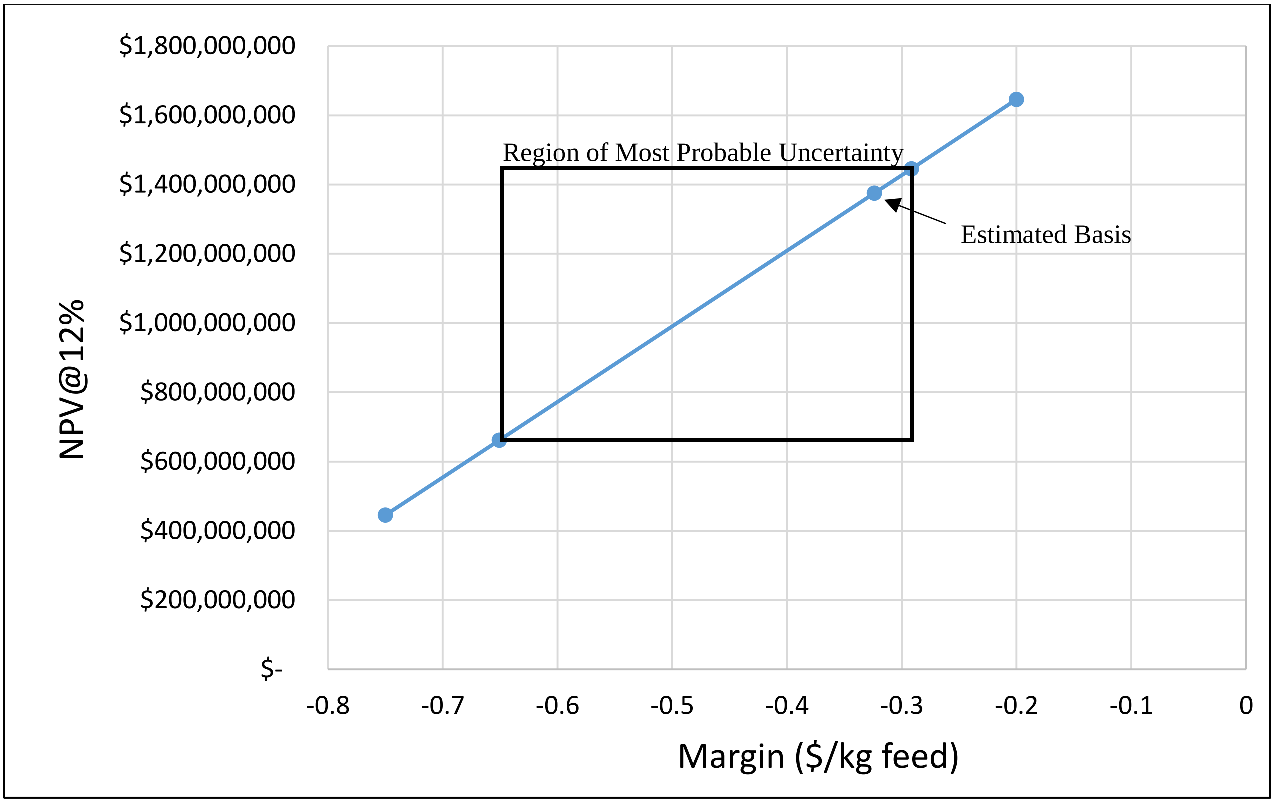


Figure 15. Sensitivity analysis for margin between transportation fuels and soybean oil for the heavy end processing design.

Even at the lowest margin between products and raw materials over the last six years the heavy end processing design would always be profitable. The margin would have to fall below $-0.95/kg for the process to only break even over the 20 year life cycle. This equates out to a soybean oil price of $1.20/kg (shown in Chapter V), which last happened in 2012. The probability of the margin ever getting that low appears to be unlikely, so the heavy end processing design is an economically feasible alternative.

If the margin were to ever drop down below \$-0.95/kg feed using soybean oil as a raw material, it is highly likely that changing the feedstock to waste cooking oil would result in a large enough margin to keep the process economically feasible. As described in Section VI.A., even when waste oil prices were at a high in 2013, the margin between the products and raw material was \$-0.22/kg feed, significantly higher than the breakeven margin.

The other hazard associated with the heavy end processing section would be the highly valuable byproduct mesophase pitch. The sensitivity analysis for the effect of mesophase pitch price on the NPV@12% is shown in Figure 16. The region of most probable uncertainty for the mesophase pitch price used the known manufacturing price of melt spun PAN, which is very similar to the mesophase pitch produced from this process, as the low value (\$6.55/kg) [62]. The high value was chosen to be the known high value of selling price of PAN based carbon fiber reduced by 30% to take into account the processing of the pitch into carbon fibers (\$21/kg) [32].

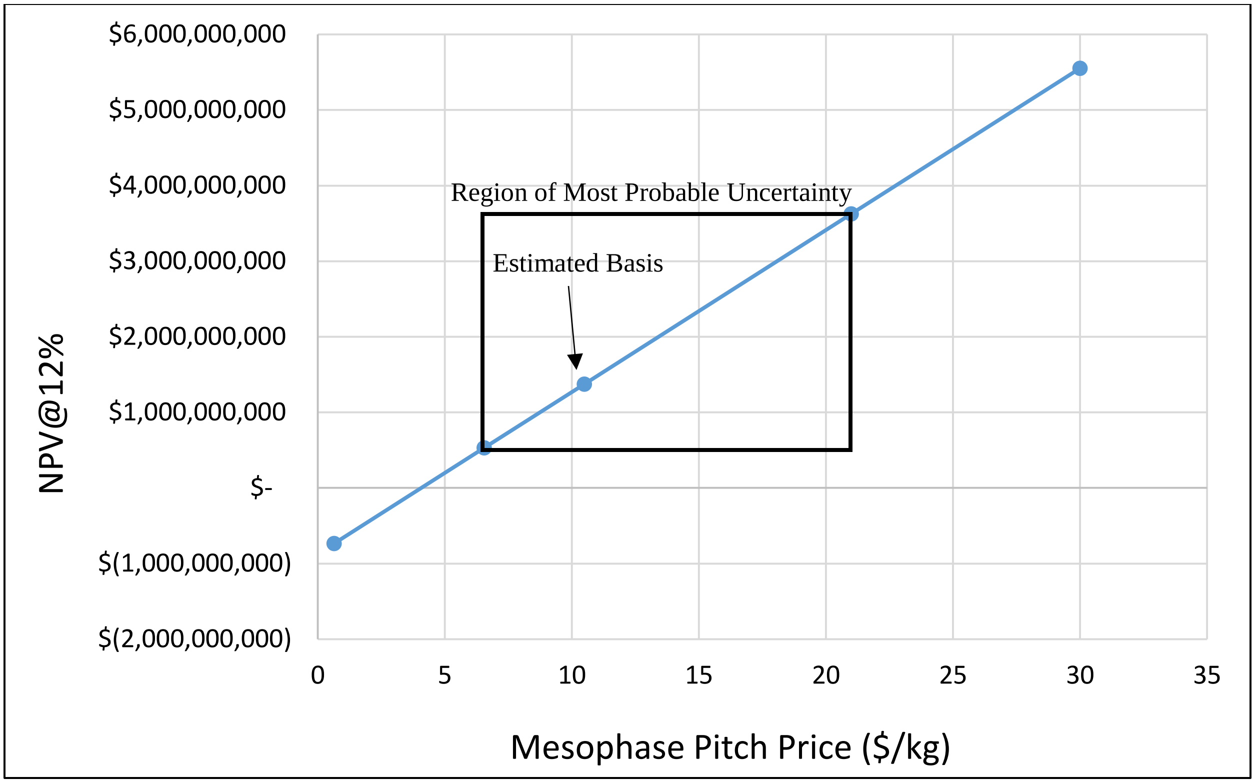


Figure 16. Sensitivity analysis for mesophase pitch price on NPV@12% for the heavy end processing design.

The price of mesophase pitch, and melt spun PAN, is highly dependent on carbon fiber market conditions. However, it would be highly unlikely that the sale price of mesophase pitch would ever drop to the low end price of $6.55/kg. This is because this price is the straight manufacturing price, which is the manufacturers cost to produce, and no manufacturer would produce a product for no profit. In addition, the estimated basis point of $10.50/kg is an accurate assumption for the price of mesophase pitch. This value is a justifiable increase from the manufacturing cost of the product. In addition, the $10.50/kg is a 30% reduction in cost from the current sale price of PAN based carbon fiber ($15/kg). This 30% reduction should take into account any manufacturing costs associated with the conversion of the pitch into the carbon fiber product.

Figure 16 shows that even if the mesophase pitch were sold at an all-time low, the process would still be profitable over the 20 year life cycle, which would be highly unlikely as explained above. This in turn indicates that there is no economic risk surrounding the sale price of mesophase pitch, which again shows that the heavy end processing design is an economically feasible alternative regardless of mesophase pitch price and fluctuation in margin between the transportation fuels and raw materials.

In addition to the margin between products and raw materials and the price of mesophase pitch, the FCI for the design could potentially affect the profitability of the investment. Figure 17 displays the sensitivity analysis for the effect of the FCI on the NPV@12% of the process over the 20 year life cycle. The region of most probable uncertainty for the FCI is defined by ±40%. If the FCI was 40% higher at $154 million, the NPV@12% would be $1.33 billion ± 40%. If the FCI was 40% lower at $66 million, the NPV @ 12% would be $1.42 billion ± 40%. The breakeven point for the FCI is $1.45 billion ± 40%, indicating very little economic risk associated with the FCI for the process.

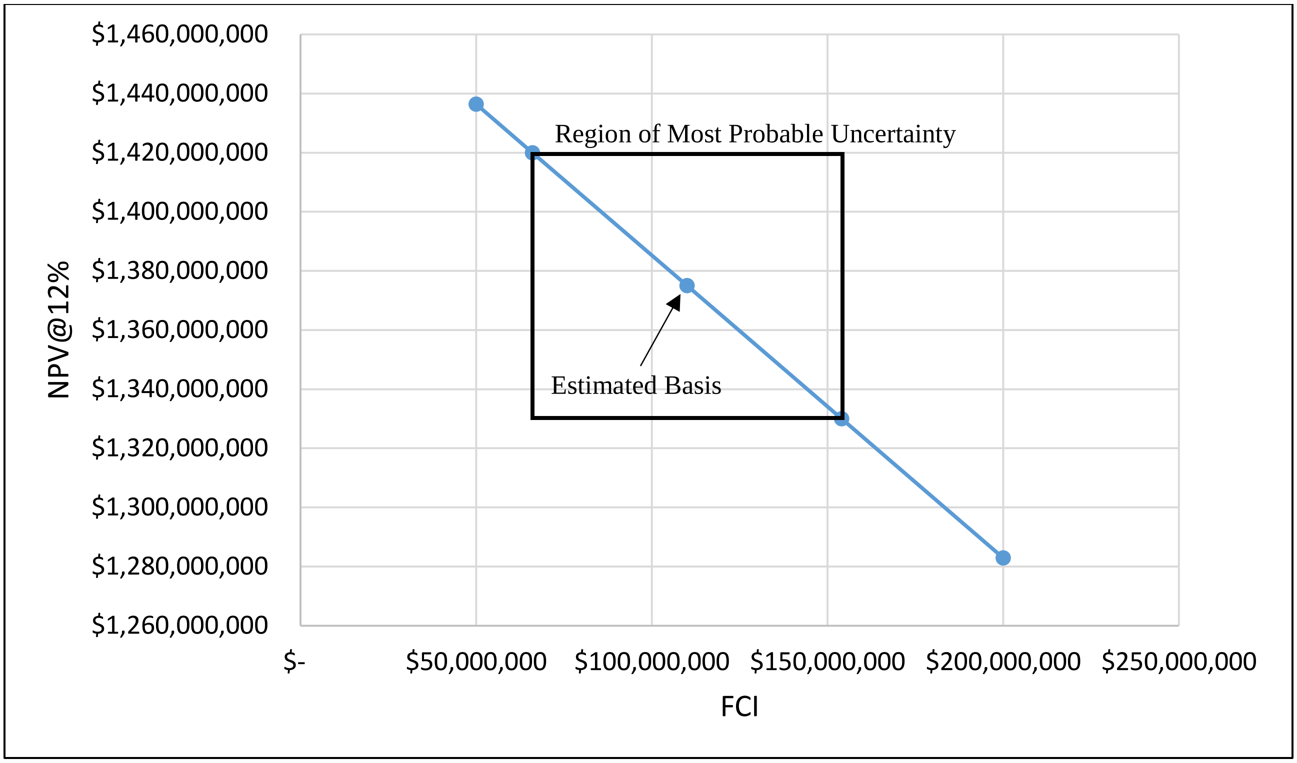


Figure 17. Sensitivity analysis for the FCI on the NPV@12% for the heavy end processing design.

VII.D. Integrated Soybean Oil Processing Hazard Analysis

Chapter VI of this thesis introduced the integration of the biorefineries designed with a previously designed soybean oil processing plant. The economic analysis surrounding these designs were also developed and presented in Chapter VI. The following section presents the hazards associated with the heavy end processing design integrated with the soybean oil processing plant.

The main hazards to the investment are the margin between the raw material price (soybeans) and transportation fuel products, the sale price of mesophase pitch, and the sale price of soybean meal. Figure 18 plots the margin vs. time based on the fuel yields of the heavy end processing design (Chapter V) produced per kilogram of soybeans processed. As seen from Figure 18, the current margin between fuel products and soybeans is relatively high.

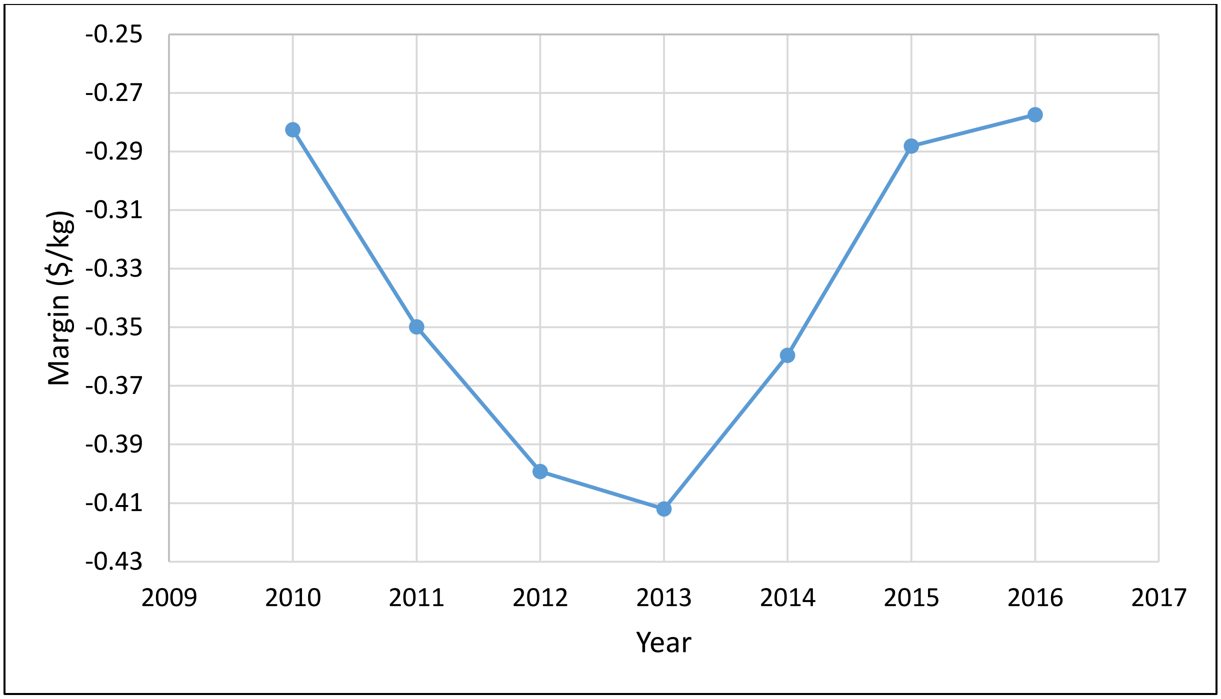


Figure 18. Margin of transportation fuels and soybeans on a mass basis for heavy end processing design integrated with soybean oil processing.

The sensitivity analysis of the margin on the NPV @ 12% for the heavy end processing design integrated with soybean oil processing is shown in Figure 19. The region of most probable uncertainty for the margin is the high value (current prices used) and low value (from 2013) seen over the last six years. Even at the lowest margin between products and raw materials over the last six years the design is still profitable. The margin would have to fall below $-0.53/kg for the process to only break even over the 20 year life cycle. This would equate out to a soybean price of $0.60/kg (Chapter VI), which last happened in October, 2012, and is very close to an all time high for soybean prices.

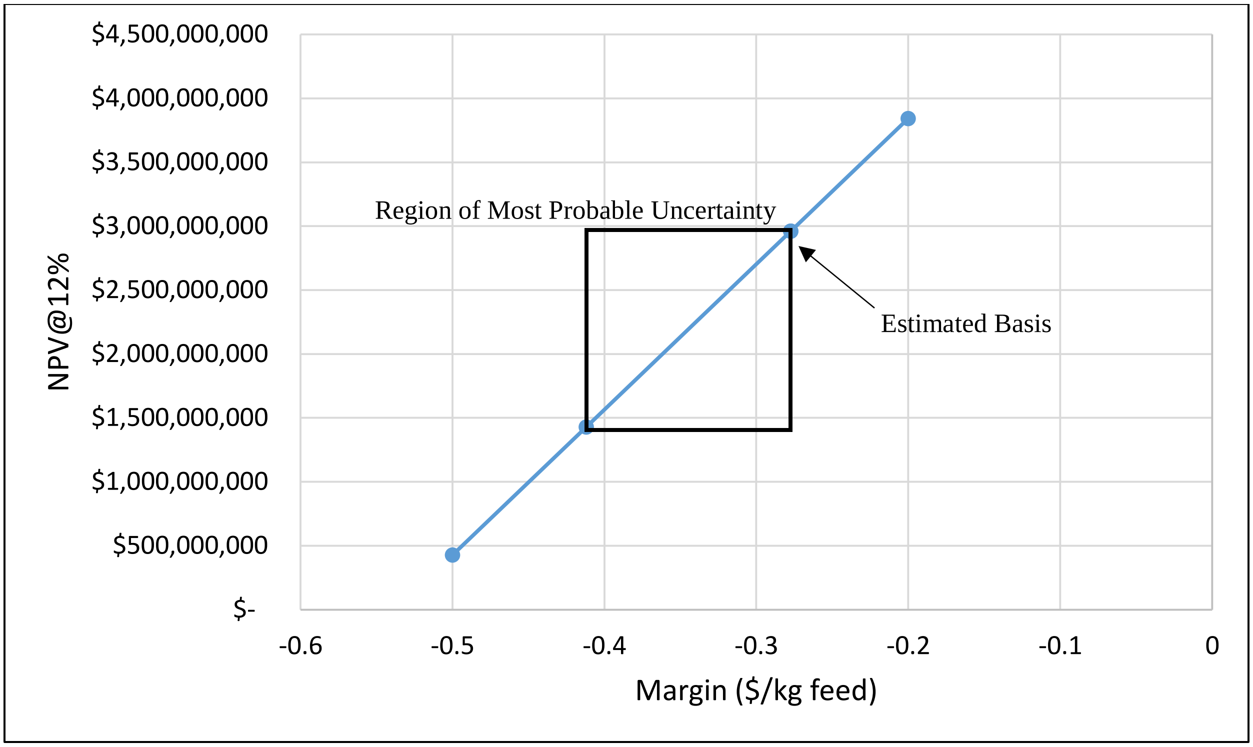


Figure 19. Sensitivity analysis for the margin on the NPV@12% for the heavy end processing design integrated with the soybean oil processing plant.

Another hazard associated with the heavy end processing design integrated with soybean oil processing would be the highly valuable byproduct of mesophase pitch. The sensitivity analysis for mesophase pitch price on the NPV@12% is shown in Figure 20. The region of most probable uncertainty for the mesophase pitch price used the known manufacturing price of melt spun PAN, which is very similar to the mesophase pitch produced from this process, as the low value ($6.55/kg) [62]. The high value was chosen to be the known high value of selling price of PAN based carbon fiber reduced by 30% to take into account the processing of the pitch into carbon fibers ($21/kg) [32].

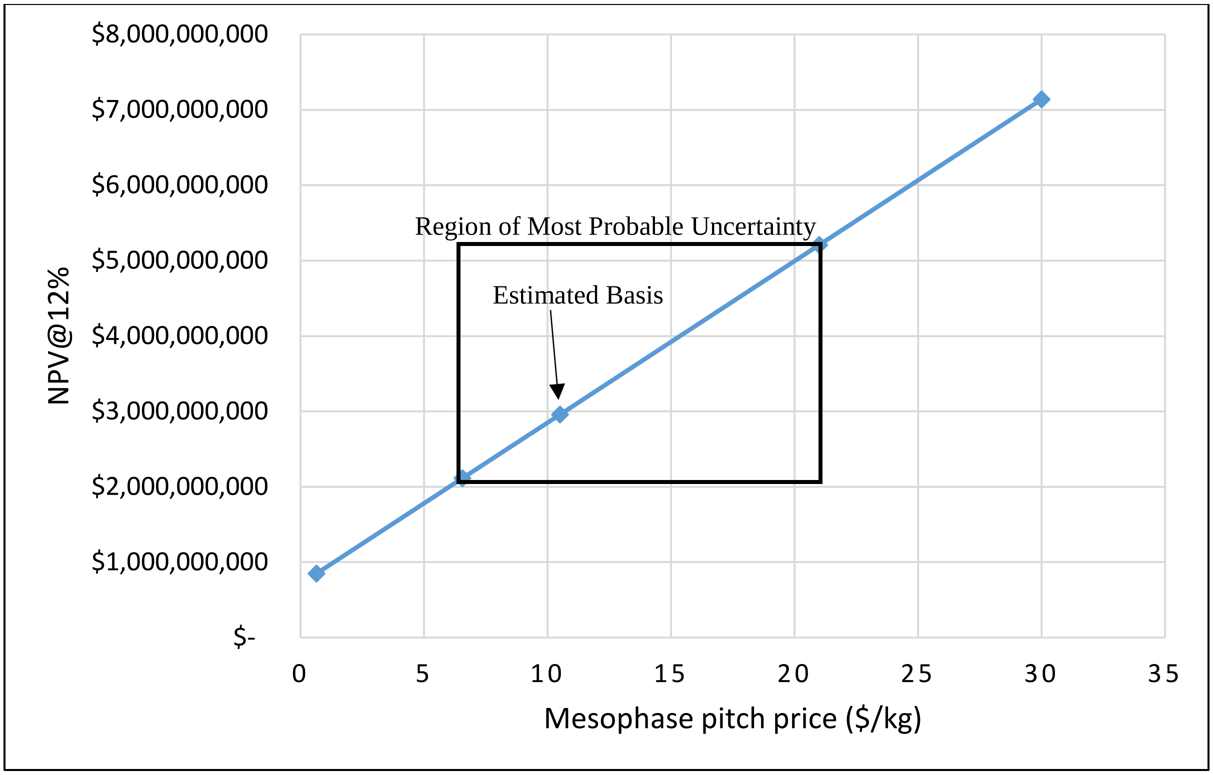


Figure 20. Sensitivity analysis for mesophase pitch price on NPV@12% for the heavy end processing design with soybean oil processing.

The price of mesophase pitch, and melt spun PAN, is highly dependent on carbon fiber market conditions. However, it would be highly unlikely that the sale price of mesophase pitch would ever drop to the low end price of $6.55/kg. This is because this price is the straight manufacturing price, which is the manufacturers cost to produce, and no manufacturer would produce a product for no profit. In addition, the estimated basis point of $10.50/kg is an accurate assumption for the price of mesophase pitch. This value is a justifiable increase from the manufacturing cost of the product. In addition, the $10.50/kg is a 30% reduction in cost from the current sale price of PAN based carbon fiber ($15/kg). This 30% reduction should take into account any manufacturing costs associated with the conversion of the pitch into the carbon fiber product.

Figure 20 shows that even if the mesophase pitch were sold at an all-time low, the process would still be profitable over the 20 year life cycle, which would be highly unlikely as explained above. This in turn indicates that there is no economic risk surrounding the sale price of mesophase pitch, which again shows that the heavy end processing design integrated with the soybean oil processing plant is an economically feasible alternative.

The other major revenue producer for the integrated process is the byproduct of soybean meal. The sensitivity analysis for the price of soybean meal on NPV@12% is shown in Figure 21. The region of most probable uncertainty is based on the lowest sale price of soybean meal seen in the last six years ($280/ton) and the highest over the last six years ($605/ton) [56]. Figure 21 shows that even if soybean meal reached the lowest point seen in the last six years the process would still be profitable over the 20 year lifecycle. The sale price of soybean meal would have to drop below $120/ton for the process to break even over the lifecycle of the plant. This would be an all time low for soybeans, and it is highly unlikely that prices would drop this low.

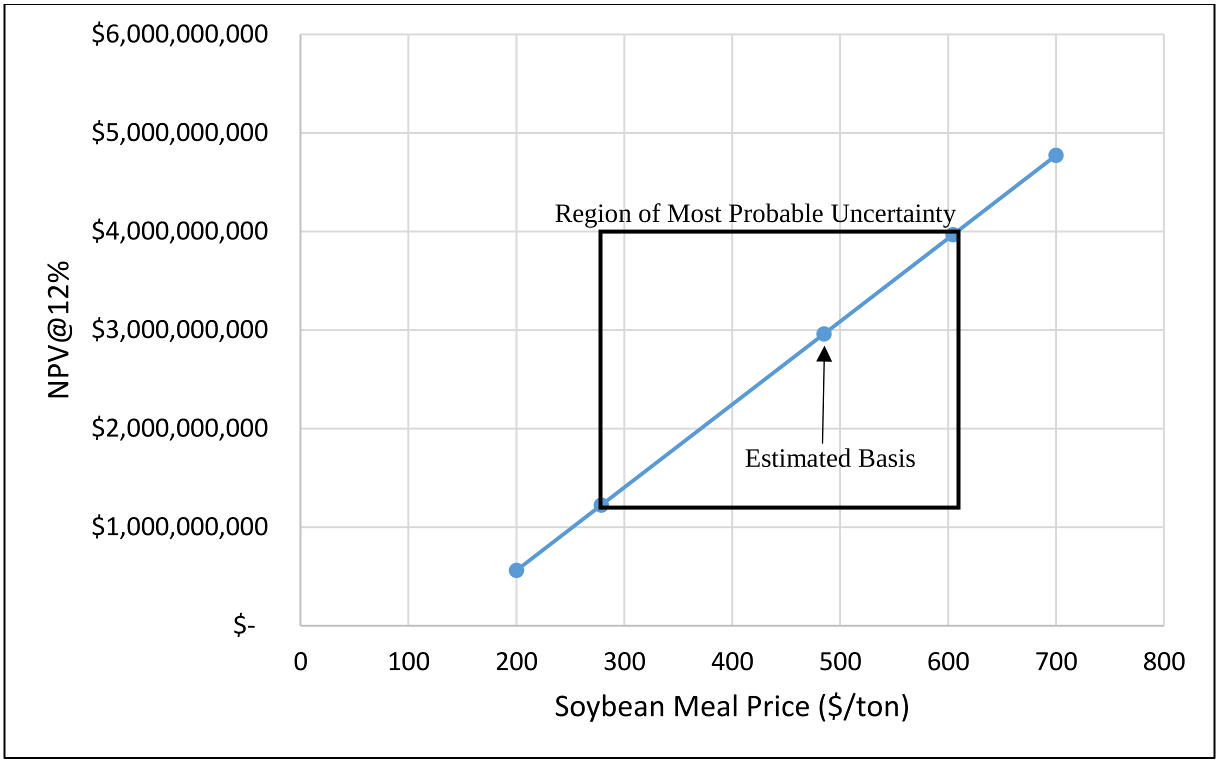


Figure 21. Sensitivity analysis for soybean meal sale price on NPV@12% for the heavy end processing design with soybean oil processing.

Based on the analysis of margin, mesophase pitch sale price, and soybean meal sale price, the heavy end processing design integrated with the soybean oil processing plant is highly attractive from an economic standpoint.

CHAPTER VII

CONCLUSIONS

Three alternatives of a preliminary design and economic assessment of a biorefinery based on the noncatalytic cracking of triglyceride oils were developed. The base design maximized the production of transportation fuels with limited byproducts. The economic analysis performed on this design showed that, using current food grade soybean oil raw material prices this design is not economically feasible, producing a NPV@12% of $(820 million) ± 40%. This represents a near worst case scenario, as the process does not require feedstock of this quality.

One way to make the process more economically feasible, is the development of processes that produce more profitable byproducts. The design of a biorefinery that includes fatty acid recovery resulted in a process that produces a NPV@12% of $340 million ± 40%. This process extracted and recovered the short and medium chain fatty acids produced during the cracking, as well as production of transportation fuels. Another option is to expand heavy end processing of the vacuum bottoms into the saleable byproduct of mesophase pitch. Adding this to the base design previously produced leads to a NPV@12% of $1.4 billion ± 40% over the 20 year life cycle. A fully configured biorefinery combining these two options leads to an even higher profitability.

Following the preliminary design and economic assessment on each alternative, an economic hazards analysis was performed. The major hazard associated with the biorefineries is the margin between the TAG oil price and the price of the transportation fuels produced. A sensitivity analysis on this margin for the base design showed that it is highly unlikely this design could be profitable using soybean oil as the raw material. However, based on waste cooking oil trends, the use of a lower priced TAG oil feedstock could provide a margin that would enable the process to be profitable.

The sensitivity studies performed on the fatty acid recovery design showed that at the current gross margin the process is profitable, but if the margin were to lower the process would no longer remain profitable. The use of waste cooking oils, or other lower value oils, would provide a process that would remain profitable even with fluctuations in raw material and product prices. Also, the hazard analysis surrounding the heavy end processing design showed that soybean oil would have to reach an all time high for the process to ever become nonprofitable. In addition, the saleable byproduct of mesophase pitch could drop below the manufacturing cost and the process would still be profitable, providing an economically feasible alternative regardless of fluctuating prices.

Additionally, the integration of any of these biorefineries with a previously developed soybean oil processing plant showed that combining the two designs results in economically feasible alternatives with and without additional byproduct production. Combining the design of a world scale soybean oil processing plant with any of the biorefinery alternatives does result in a highly complex facility. The combination of the biorefineries with smaller, less complex oilseed processing plants has the potential to provide a less complex design while still producing the larger profits associated with the integrated plant.

It is important to note that the current economic analysis was performed conservatively using no tax credit or subsidies. Under the current federal tax law there is a $0.13/L incentive for alternative fuel sold, and the IRS definition for alternative fuel includes liquid hydrocarbons derived from biomass, which includes the production of renewable fuels from soybeans [63, 64]. Therefore, including this tax incentive into the economic analysis of all three designs will help to improve the profitability of the biorefineries.

Additional refinement of the previously collected data used to design the biorefineries should be performed before further development of the processes. In particular, the decarboxylation reactors designed should be tested further to refine the operating conditions and catalysts chosen for the process.

The addition of the heavy end processing to the biorefinery scheme provides significant economic advantages. Further exploration of this technology should be performed to ensure the production of a suitable mesophase pitch could be achieved on a world scale size. This work has the potential to modify the current preliminary designs to drive the process to produce larger volumes of tar, which in turn would produce increased amounts of mesophase pitch. This increased pitch production would then result in significant increases in revenues for the biorefineries.

Finally, full pilot scale testing of the reactions simulation of discounted TAG oils should be performed so a transportation fuel yield can be found for each oil. This fuel yield will enable the evaluation of a more accurate gross margin analysis on each oil to verify the use of discounted oils will provide a solution to make all alternatives economically feasible.

APPENDICES

Appendix A. Alternative Base Design of a Biorefinery Based on the Noncatlytic Cracking of Tryglyceride Oils

The base design for a biorefinery based on the noncatalytic cracking of TAG oils includes the production of transportation fuels and limited byproducts without the production of any additional byproducts that reduce the quantity of fuel products. An alternative base design was also produced that produces the additional byproducts of C5 product and C6 nonaromatic raffinate. These additional byproducts lessen the production of transportation fuels. The goal of the base design is to maximize the production of these fuels, so this design was produced as an alterative with the production of addition byproducts.

The following sections describe the process used to develop a preliminary design and economic assessment for the alternative base design of a biorefinery based on the noncatalytic cracking of triglyceride oils. Section A.1 reviews the preliminary design of the biorefinery, Section A.2 describes the economic assessment performed based on this design, and Section A.3 examines the profitability of the process and describes possible ways to increase its profitability.

A.1. Process Design

The design provided is specifically based on a feed of soybean oil. However, any triglyceride (TG) oil, unsaturated fatty acid, or carboxylic acid (e.g. lipids) can be used. Differences in the product rates and slight differences in the reaction temperatures are the only expected variations based on feedstock. A 7500 MTPD soybean oil extraction plant can efficiently produce 600,000 m^3/year of crude soybean oil [56]. The typical composition of this soybean oil can be found in Table A.1. The crude soybean oil feed, shown in Table A.2, can then be noncatalytically cracked into naphtha which is a gasoline blend compound, plus transportation fuel quality kerosene and diesel oils. Kerosene is the primary compound of jet fuel. The flow rates of the most significant products can be found in Table A.3. All products produced are in compliance with the fuel ASTM standards. The properties of these streams can be found in Tables A.4-6. Other possibilities, not directly addressed in this design are other kerosene products and diesel no. 1.

In addition to the production of transportation fuels, the byproducts of butane, C5 product, nonaromatic C6 raffinate, vacuum bottoms, and acetic acid are produced. The flow rates of all byproducts can be found in Table A.7, and the ASTM properties of butane can be found in Table A.8. This process also produces two streams that are used as boiler feed for the plant. These streams can be found in Table A.9. The input/output diagram (drawing 00-A-007) shows the overall mass balance and mass flow rates of the inputs and outputs to the process.

Catalyst is used in the decarboxylation reactions, and is used to convert the carboxylic acids that are produced during the noncatalytic cracking of the soybean oil into alkanes. The amount of catalyst used for the process can be found in Table A.10, and the utilities required are presented in Table A.11.

The process was designed as four core subsystems. The first subsystem consists of the thermal cracking section. In this section the incoming soybean oil is cracked into a three phase product through the use of noncatlytic cracking at high temperatures. The majority of the molecules are cracked into the C5-C16 range. The next subsystem is the purification section. In this section the light ends and heavy ends are separated from the middle distillates, which are known as organic liquid product (OLP). The OLP is then sent through the next subsection, decarboxylation. In this area the carboxylic acids are converted into hydrocarbons and the alkenes are hydrogenated into alkanes through the use of steam. Following decarboxylation, the OLP's are sent to the final subsystem, trim purification. In this section the OLP's are purified into transportation fuel products, and the light ends and heavy ends are purified into saleable byproducts.

All separation and reaction unit operations that are required for the process are shown in the quantitative block flow diagram (BFD). This drawing also shows the mass balance for the individual process areas. The thermal cracking and purification subsections are shown on Drawing 00-A-008/sheet 1, and the decarboxylation and trim purification subsections are shown on sheets 2-4.

Drawings 0X-A-009/X show the process flow diagrams for the process. The following detailed process description is based off of the process flow diagrams. Table A.12 displays the equipment lettering system, Table A.13 shows the equipment number codes, and Table A.14 presents an example equipment number scheme. These tables explain how the equipment in Tables A.15-22 were coded. Table I.6 in Appendix I shows examples of all the equipment used in the drawings. Table A.23 shows the drawing number codes, and Table A.24 displays an example of how the drawings are named.

A.1.i. Thermal Cracking Section (Drawings 01-A-009/X)

TG oil is assumed to enter the process from storage at 1000 kg/min, a temperature of 20 °C, and a pressure of 140 kPa (stream 1). In order to heat the incoming oil to the desired temperature (410 °C) it is first sent through the post cracking cooler (E-201 A/B). This heat exchanger uses the excess heat of the products coming out of the TTCR (R-101) in stream 11 to preheat the feed. E-201 A/B heats the oil to 310 °C, and then it is pressurized to the reaction pressure of 1930 kPa by L-101 A/B. Following the pre-cracking pump, the oil is heated to the desired temperature of 410 °C in E-502 A/B. The soybean oil then enters the TTCR (R-101) in Stream 8 on Drawing 01-A-009/2 at 410 °C and 1900 kPa.

The Turbulent Tubular Cracking Reactor is used to noncatalytically crack the TG oil into transportation fuel intermediates. The majority of these molecules are in the C5-C16 carbon number range. This reactor was designed to be 6.1 m in diameter and 12.2 m in length with 10300 tubes. It operates at a temperature of 430 °C and 1800 kPa, and has a residence time of 1.17 hr. The soybean oil and crackate flow through the tube side of the reactor, and the superheated steam (435 °C and 6000 kPa) that heats the reactor flows through the shell side. The products leaving the reactor are used to heat the incoming soybean oil in E-201 A/B, and are then sent to the purification section of the plant in Stream 12 at 1000 kg/min, 230 °C, and 1760 kPa.

A.1.ii. Purification Section (Drawings 02-A-009/X)

Following the thermal cracking section of the plant is the purification section. In this section the middle distillates are separated from the light and heavy ends. First, the cooled TTCR products (Stream 12) are sent to the acetic acid flash 1 (D-107). In this flash drum the majority of the C1-C8 carbon length molecules (Stream 17) are flashed off of the remaining C7-C50 molecules by flashing the incoming stream to 1380 kPa. In addition to the removal of the lighter compounds, some of the acetic acid that is produced in the TTCR separates out from the organic phase. This aqueous acetic acid, with small amounts of propionic acid, are removed from the organic liquid product in Stream 15. The organic liquid is then flashed again in D-101 at 690 kPa. In this flash drum the remaining lighter molecules are removed in Stream 19, leaving the liquid products in Stream 18. Stream 17 and 19 are then sent to D-108 on Drawing 02-A-009/3, and Stream 18 is sent to E-202 A/B on Drawing 02-A-009/2.

Stream 18 is first cooled to 150 °C in E-202 A/B, and is then flashed a third time in D-102. This flash drum operates at 140 kPa. The liquid products are then sent to the atmospheric distillation column on Drawing 02-A-009/4 in Stream 23. The gas products from D-102 are first compressed by G-101 A/B to 410 kPa, and are then sent to D-108 on Drawing 02-A-009/3 in Stream 25.

Streams 17 and 19 from sheet 1 are sent into acetic flash drum 2 on Drawing 02-A-009/3. Stream 25 from sheet 2 is also sent into this flash drum. D-108 removes the light ends in the C1-C6 carbon range in the gas product in Stream 56. The remaining C6-C8 organic liquid is removed in Stream 57. D-108 also has a small amount of acetic and propionic acid, which separate out from the organic liquid phase into an aqueous phase. This product (Stream 58) is combined with Stream 15 in D-310 to produce the acetic acid byproduct for sale at 5 kg/min. Stream 56 is then sent to Drawing 05-A-009/1 for light end purification, and Stream 57 is sent to Drawing 03-A-009/1 for decarboxylation.

The atmospheric distillation column (D-201), shown on Drawing 02-A-009/4, separates the naphtha/kerosene range fuel intermediates from the heavier diesel fuel range intermediates. D-201 splits the incoming Stream 23 at the C12-C13 carbon range. The distillate products (C7-C12) leave the top of the column at 210 °C and 124 kPa. They are first condensed at 60 °C in E-101 A/B and pressurized to 140 kPa by L-104 A/B prior to being sent to decarboxylation in Stream 29 at 170 kg/min. The bottoms from D-201 exit the column at 280 °C and 140 kPa. They are then heated to 310 °C in E-401 A/B and depressurized to 140 kPa by L-105 A/B before being sent to vacuum distillation in Stream 33 at 590 kg/min. D-201 is 8.5 m tall, 2.4 m in diameter, and has 7 trays. The feed enters the column at tray 3, and the column operates with a reflux ratio of 0.1.

Stream 33 enters the vacuum column (D-202) on Drawing 02-A-009/5 at tray 5. D-202 operates at 30 kPa, and has a height of 20.4 m, diameter of 2.9 m, and 20 trays. D-202 separates the diesel range fuel intermediates from the heavy end byproducts. This separation occurs at the C30 range, with the diesel fuel intermediates leaving in the distillate (C12-C30), and the heavy ends leaving the bottom (C30-C50). The distillate leaves D-202 at 260 °C and 20 kPa. It is then cooled to 230 °C in E-102 A/B. The reflux is then sent back to the column at a reflux ratio of 1.3, and the distillates head to decarboxylation at 230 °C, 140 kPa and 320 kg/min in Stream 49. The bottoms exit D-202 at 330 °C and 34 kPa. They are then heated to 340 °C in E-402 A/B, and the Vacuum Bottoms (Stream 41) byproduct is pressurized to 140 kPa by L-107 A/B before being sold at a rate of 280 kg/min.

A.1.iii. Decarboxylation Section (Drawings 03-A-009/X)

Stream 57 from D-108 on Drawing 02-A-009/3 and Stream 29 from L-104 A/B on Drawing 02-A-009/4 combine to form Stream 59 (220 kg/min) prior to being sent through the naphtha decarboxylation reactor (R-102 A/B). These streams combine to 60 °C and 140 kPa, and are then pressurized to 2400 kPa by L-103 A/B. Next, the stream must be heated to the reaction temperature. This is achieved by E-503 A/B, which it heats the reactor feed stream to 320 °C before it is fed into the reactor. Process steam at 315 °C and 2200 kPa also enters the reactor at a flow rate of 7 kg/min to provide a hydrogen donor source. The steam and feed stream react in R-102 A/B to convert any carboxylic acids that were produced from the noncatlytic cracking in R-101 into alkanes. The steam also reacts with a majority of the alkene molecules and forms alkanes of the same carbon chain length. This results in a significant amount of CO2 produced, as well as smaller fuel intermediate molecules (C1-C6). R-102 A/B is 2.7 m in diameter and 17 m in length with a catalyst volume of 220 m^3. The products exit the reactor in Stream 65 at 320 °C and 2200 kPa at a flow rate of 230 kg/min and proceed to E-109 A/B on Drawing 03-A-009/3.

Stream 49 from L-108 A/B on Drawing 02-A-009/5 flowing at a rate of 320 kg/min is first pressurized to 2400 kPa by L-109 A/B on Drawing 03-A-009/2. Then it is heated to 320 °C in E-504 A/B prior to entering the diesel decarboxylation reactor (R-103 A/B). Process steam in stream 70 also enters R-103 A/B. It enters at a flow rate of 10 kg/min at 315 °C and 2200 kPa. As in R-102 A/B, R-103 A/B reacts the feed stream with the process steam to convert any carboxylic acids and alkene molecules that were produced during the noncatalytic cracking into alkanes. R-103 A/B is 3.4 m in diameter and 19 m in length with a catalyst volume of 310 m^3. The products exit the reactor in Stream 71 at 320 °C and 2200 kPa at a flow rate of 330 kg/min. They then proceed to the purification section, shown starting on Drawing 03-A-009/4, for removal of light end products that were formed in the reactor.

Stream 65 from R-102 A/B shown on Drawing 03-A-009/1 is first cooled to 93 °C by E-209 A/B prior to entering Flash 7 (D-109). D-109 flashes the incoming feed to 170 kPa, and separates the light components formed during decarboxylation (C1-C4) from the naphtha range fuel intermediates (C4-C12). The gas products from D-109 exit in Stream 4 at 82 °C and 170 kPa and head to light end purification shown on Drawing 05-A-009/1 at a flow rate of 45 kg/min. The liquid products exit D-109 at 82 °C and 170 kPa in Stream 3. They then combine with Stream 74 from D-105 on Drawing 05-A-009/1 to form Stream 78 at 210 kg/min. Stream 78 then goes to D-203 on Drawing 04-A-009/1 for trim purification.

Stream 71 from R-103 A/B on Drawing 03-A-009/2 is first cooled to 177 °C by E-208 A/B as shown on Drawing 03-A-009/4. It is then sent to flash 3 (D-103) to remove the majority of the light end products. D-103 flashes the incoming stream from 2170 kPa to 1720 kPa. The light ends exit D-103 in Stream 82 at 24 kg/min and 175 °C, and are sent to E-207 A/B on Drawing 05-A-009/1 for light end purification. The liquid products From D-103 enter D-104 and are further flashed to 103 kPa. Flash drum 4 removes any remaining light ends in the diesel fuel intermediates. The light ends exit D-104 in Stream 84 at 170 °C and a flow rate of 10 kg/min, and are pressurized to 240 kPa by G-103 before being sent to light end purification shown on Drawing 05-A-009/1. The liquid products exit D-104 at 170 °C at a flow rate of 290 kg/min, and are sent to trim purification on Drawing 04-A-009/3.

A.1.iv. Trim Purification Section (Drawings 04-A-009/X)

Stream 78 from Drawing 03-A-009/3 enters the hexane splitter column (D-203) shown on Drawing 04-A-009/1. D-203 separates the lighter components of Stream 78 (compounds C1-C6) from the naphtha-diesel range (compounds C7-C12). D-203 is 11.9 m tall, with a 1.5 m diameter, 12 trays, and the feed enters the column on tray 4. The distillate products exit the column at 67 °C and 165 kPa. They are then partially condensed to 34 °C by E-108 A/B. The resulting gaseous distillate product leaves the reflux drum (D-303 A/B) in stream 94 at 14 kg/min, and is sent to light end purification on Drawing 05-A-009/1. The reflux is pumped back to the column at a reflux ratio of 1.8 through L-126 A/B. The bottoms, Stream 150, exit D-203 at 140 °C and 170 kPa. They are then heated to 160 °C by E-406 A/B prior to being pumped to D-205 on Drawing 04-A-009/2 by L-117 A/B in Stream 150 at 190 kg/min.

Stream 150 enters the naphtha-jet cut column (D-205) shown on Drawing 04-A-009/2. D-205 separates the naphtha product (C7-C9) from the jet fuel product (C9-C12). D-205 has a height of 27.4 m, diameter of 1.4 m, 30 trays, and a feed tray of 7. The distillate exits D-205 at 135 °C and 120 kPa. It is then cooled to 117 °C by E-105 A/B, and pumped to 140 kPa by L-119 A/B. The distillate in Stream 156 then is sent to E-212 A/B shown on Drawing 04-A-009/6 at a rate of 68 kg/min, and the reflux is sent back to the column in Stream 157 at a reflux ratio of 1.25. The bottoms exit D-205 at 203 °C and 130 kPa. They are then heated to 204 °C by E-403 A/B and pumped to 193 kPa by L-120

A/B. The bottoms in Stream 163 are then sent to E-213 A/B shown on Drawing 04-A-009/6 at a rate of 120 kg/min.

Stream 85 shown on Drawing 03-A-009/4 is first pumped to 210 kPa by L-110 A/B, shown on Drawing 04-A-009/3. It is then heated to 204 °C by E-505 A/B before it is sent to the jet diesel cut column (D-204) shown on Drawing 04-A-009/4. Stream 167 is sent to D-204 at 204 °C and 170 kPa at a rate of 290 kg/min.

Stream 167 enters D-204 on tray 13. D-204 splits the jet fuel product (C8-C15) from the diesel fuel no. 2 product (C16-C30). D-204 is 24.2 m tall, 2.6 m in diameter, and has 25 trays. The distillate exits D-204 at 230 °C and 117 kPa. It is then cooled to 40 °C by E-103 A/B, and pressurized to 130 kPa by L-112 A/B. The distillate products leave the top in Stream 172 at a rate 73 kg/min. The reflux is then pumped back through the column in Stream 173 at a reflux ratio of 2.7. The bottoms exit the column at 290 °C and 140 kPa, and are heated to 300 °C by E-404 A/B. The bottoms are then pumped to 170 kPa in Stream 178 by L-113 A/B at a flow rate of 220 kg/min. Stream 178 then enters the diesel fuel oil cut column (D-206) shown on Drawing 04-A-009/5.

D-206 (Drawing 04-A-009/5) splits the diesel fuel range intermediates from the bottom fuel oil intermediates. This column is 37.8 m tall, 2.7 m in diameter, has 40 trays, and a feed to tray 28. The diesel fuel range molecules (C16-C21) exit the top of the column at 340 °C and 145 kPa. They are then cooled to 320 °C by E-107 A/B prior to being pressurized to 17 kPa by L-114 A/B. The reflux is then sent back to the column at a reflux ratio of 0.8, and the diesel fuel intermediates are sent to E-214 A/B shown on Drawing 04-A-009/7 in Stream 184 at a flow rate of 210 kg/min. The fuel oil intermediates flow out the bottom of the column at 398 °C and 170 kPa. They are then heated in the reboiler (E-409 A/B) to 400 °C. The fuel oil intermediates are then pumped to 210 kPa by L-115 A/B, and are sent to E-215 A/B shown on Drawing 04-A-009/7 in Stream 191 at a flow rate of 5 kg/min.

Stream 156, shown on Drawing 04-A-009/2, is cooled to 55 °C by E-212 A/B, as shown on Drawing 04-A-009/6. The naphtha stream product is then pumped to 170 kPa in Stream 199 at a flow rate of 68 kg/min and is sent to storage to await sale. Stream 163 from L-120 A/B on Drawing 04-A-009/2 and Stream 172 from L-112 A/B on Drawing 04-A-009/4 combine to form Stream 192 on Drawing 04-A-009/6. This stream is then cooled to 55 °C by E-213 A/B, and pressurized to 170 kPa by L-118 A/B. Stream 200 is the jet fuel product steam, and is sent to storage at a rate of 200 kg/min to await sale.

Stream 184 is routed from L-114 A/B, as shown on Drawing 04-A-009/5, to E-214 A/B and is cooled to 55 °C. This stream, Stream 201, is then sent to storage as the diesel fuel no. 2 product at a rate of 210 kg/min. Stream 191 from L-115 A/B on Drawing 04-A-009/5 is cooled to 55 °C by E-215 A/B on Drawing 04-A-009/7. The stream exiting the fuel oil cooler (E-215 A/B), Stream 204, is fuel oil no. 5, and is sent to the boiler to serve as fuel at a rate of 5 kg/min.

A.1.v. Light End Processing Section (Drawing 05-A-009/X)

Stream 82 from D-103 on Drawing 03-A-009/4 is cooled to 37 °C in E-201 A/B shown on Drawing 05-A-009/1 prior to entering flash 5 (D-105). Streams 86 from G-103 and 56 from D-108, shown on Drawings 03-A-009/4 and 02-A-009/3, respectively, combine together and then enter D-105. D-105 separates the naphtha range fuel intermediates (C6-C7) from the light ends (C1-C5). The naphtha range intermediates exit D-105 out the bottom at 21 °C and 103 kPa in Stream 73. Stream 73 then proceeds to L-

116 A/B shown on Drawing 03-A-009/3 at 23 kg/min. Stream 92 exits the top of D-105 at 21 °C and 103 kPa, and combines with Streams 94 from D-303 and 4 from D-109 on Drawings 04-A-009/1 and 03-A-009/3, respectively. The three streams combine to form Stream 93, which is at 24 °C and 103 kPa, which flows to G-105, shown on Drawing 05-A-009/2, at 240 kg/min.

Stream 93 enters the light end compressor (G-105) shown on Drawing 05-A-009/2. G-105 is a three stage compressor. The stream is pressurized to 413 kPa and heated to 137 °C in the first stage. It is then cooled by the interstage cooler 1 (E-210 A/B) to 35 °C before entering the second stage of the compressor. The stream is then pressurized to 1520 kPa in stage two, and is also heated to 180 °C. It then flows through the interstage cooler 2 (E-211 A/B), and is cooled to 35 °C before entering the third stage. Stream 105 then exits G-105 at 155 °C and 3200 kPa, and proceeds to the syngas column (D-207), see Drawing 05-A-009/3, at 240 kg/min.

Stream 105 is first cooled to 32 °C by E-204 A/B on shown Drawing 05-A-009/3. It then enters the syngas column (D-207) on tray 5. D-207 is 36.6 m tall and 2.1 m in diameter with 40 trays. The syngas column removes the syngas (C1-C3) from the butane, C5, and nonaromatic raffinate products. The syngas exits the top of the reactor at 15 °C and 2710 kPa, and is partially condensed to 4 °C by moderately low temperature water in E-104 A/B. The syngas product is then sent to the boiler to be used as boiler feed in Stream 110 at 160 kg/min, and the reflux is sent back into the column at a reflux ratio of 0.4. The bottom products exit D-207 at 170 °C and 2800 kPa, and are heated to 180 °C by E-405 A/B. The bottom products are then sent to the debutanizer column (D-210) in Stream 115 at a rate of 86 kg/min.

Stream 115 is first heated to 250 °C by E-205 A/B (Drawing 05-A-009/4). This stream then enters D-210 (debutanizer column) on tray 8. D-210 is 14 m tall and 3.5 m in diameter, and contains 12 trays. D-210 removes the butane product from the heavier C5 and C6 products. The butane product exits the top of D-210 at 74 °C and 830 kPa. It is then partially condensed to 70 °C by E-106 A/B. The butane product is then sent to storage in Stream 123 at 22 kg/min. The reflux is sent back to the column at a reflux ratio of 16.7. The bottoms leave D-210 at 132 °C and 850 kPa, and are heated to 141 °C by E-407 A/B. Stream 129, containing the C5 and C6 products, is then sent to the C5 product column (D-211) at a rate of 68 kg/min.

Stream 129 enters D-211 shown on Drawing 05-A-009/5. D-211 is 15.8 m tall and 1.1 m in diameter, with 17 trays. The feed enters the column on tray 10, and is separated into the C5 product and nonaromatic C6 raffinate products. The C5 product exits the top of D-211 at 46 °C and 130 kPa, and is cooled to 42 °C by E-109 A/B. The C5 product is then sent to storage in Stream 134 at a flow rate of 25 kg/min. The reflux is sent back to the column at a reflux ratio of 2.4. The nonaromatic C6 raffinate exits the bottom of D-211 at 81 °C and 144 kPa. It is then heated to 84 °C by E-408 A/B, and pressurized to 170 kPa before being sent to storage. The nonaromatic C6 raffinate is sent to storage in Stream 141 at a rate of 42 kg/min.

A.2. Economic Assessment

A.2.i Broad Cost Estimate

The capital cost summary for the base design is shown in Table A.25. This table shows the total capital investment needed to complete the project, and was developed as described in Chapter II. The FCI was found to be \$93 million, and the TCI was estimated to be \$130 million ± 40%.

A.2.ii. Raw Material and Manufacturing Cost Estimate

The raw material cost is based on purchasing crude soybean oil for \$0.12/kg [20]. The total raw material cost is \$300 million per year.

The total manufacturing cost for the base design is \$17 million per year, and \$35 million per year on years the entire catalyst bed needs to be replaced. The manufacturing cost includes chemicals and catalysts costs, operating labor costs, maintenance costs, and utility costs. Table A.26 shows the overall yearly operating expense summary for the base design. The plant has an operating factor of 95%. Intermediate results can be found in Appendix C, and communication records can be found in Appendix G.

The catalyst used for the decarboxylation reactors in the base design was a Ni catalyst. The initial charge for the catalyst (shown on the broad cost estimate) covers the total amount of catalyst needed (530,000 kg) for a price of \$19 million. This amount is charged every four years in order to recharge the catalyst. It was assumed there was a 4% yearly depletion of the catalyst that needed to be replaced for the years in between. This results in a cost of \$750,000 for those years. A quote from Johnson Matthey Catalysts was used for pricing (\$28/m^3).

The base design consists of an equivalent of 22 major unit operations, which equates to 32 new operators to cover continuous operation, as described in Chapter II. An average operator salary of \$62,800 was used, and taking into account an additional 15% for supervision, the yearly operating expense equates out to \$2,200,000 per year [53]. The maintenance costs were found to be \$5.6 million per year.

The utility costs is \$8,700,000 per year. This value includes the boiler feed water, cooling water, electricity, refrigeration, process water, and natural gas needed to run the plant. The prices for all the utilities, except the electricity and natural gas, were priced based off of Turton heuristics. The natural gas and electricity values were found from typical ND and MN values [57].

A.2.iii. Revenues

Revenue for the base design comes from the sales of jet fuel, diesel fuel no. 2, petroleum naphtha, butane, C5 product, nonaromatic raffinate, vacuum bottoms, and acetic acid. Shipping costs were not considered when calculating the amount of revenues generated.

The transportation fuels, jet fuel, diesel fuel no. 2, and petroleum naphtha, produce a revenue of \$116 million/year. This value was based on the production 53,000 liquid m^3/year of petroleum naphtha that can be sold for \$0.36/L, jet fuel at a rate of 130,000 liquid m^3/year which is sold for \$0.37/L, and diesel fuel no. 2 produced at 140,000 liquid m^3/year and sold at \$0.37/L. The remaining by products produce a revenue of \$26.9 million/year. The total annual revenue for the base design is \$140 million/year.

A.2.iv. Overall Profitability

The cash flow sheet for the base design is shown in Table A.27. The process has a net present value (NPV@12%) of \$(880 million) ±40%. The project produces a gross loss of income of \$170 million per year, and has a DCFROR value of 0. The negative NPV@HR value and a DCFROR value less than 12% show that the investment is not profitable over the project lifecycle.

A.3. Break Even Point

With the current design and prices of products and raw materials, the process cannot cover the cost of the incoming soybean oil. In order for the process to break even at the current design, the price of soybean oil would have to be at an all-time low of \$0.19/kg, or the product revenues would need to be higher. The cash flow sheet based on this raw material price is shown in Table A.28.

Table A.1. Soybean oil composition.

Component	Weight %
Linolenic Acid	12%
Linoleic Acid	51%
Oleic Acid	23%
Stearic Acid	4%
Palmitic Acid	10%

Table A.2. Raw materials list for base design.

Raw Material	Amount
Soybean Oil	600,000 m^3/year

Table A.3. Transportation fuel products from base design.

Product	Amount (liquid m^3/year)
Petroleum Naphtha	53,000
Jet Fuel	130,000
Diesel Fuel No. 2	140,000

Table A.4. Petroleum naphtha product properties from base design.

Specification	Measurement
Density at 15 °C	695 kg/m3
Total paraffins volume %	72%
Olefins volume %	0%
Aromatics volume %	3.3%
Initial boiling point	96 °C
Temperature at 5% recovered	109 °C
Temperature at 10% recovered	110 °C
Temperature at 20% recovered	111 °C
Temperature at 30% recovered	112 °C
Temperature at 40% recovered	114 °C
Temperature at 50% recovered	125 °C
Temperature at 60% recovered	126 °C
Temperature at 70% recovered	127 °C
Temperature at 80% recovered	128 °C
Temperature at 90% recovered	129 °C
Final boiling point	130 °C
Reid vapor pressure at 37.8 °C	7 kPa

Table A.5. Jet fuel product properties from base design.

Specification	Measurement
Aromatics volume %	10.1 %
Temperature at 10% recovered	177 °C
Temperature at 50% recovered	232 °C
Temperature at 90% recovered	262 °C
Final boiling point	300 °C
Flash point	55 °C
Density at 15 °C	775 kg/m3
Freezing point	-40.1 °C
Viscosity at -20 °C,	4.7 mm2/s
Net heat of combustion	43.68 MJ/kg
Smoke point	28.66 mm
Cetane number	62.2

Table A.6. Diesel fuel no. 2 product properties from base design.

Specification	Measurement
Flash point	117 °C
Water volume %	0%
Temperature at 90% recovered	332 °C
Kinematic viscosity at 40 °C	4.1 mm2/s
Cetane number	70
Aromaticity volume %	10.5 %
Cloud point	3.2 °C

Table A.7. Byproduct production in base design.

Product	Amount (liquid m^3/year)
Acetic Acid	2,900
Butane	20,000
C5 Product	20,000
Nonaromatic C6 Raffinate	33,000
Vacuum Bottoms	210,000

Table A.8. Butane product properties from base design.

Specification	Measurement
Vapor pressure at 37.8 °C	397 kPa
Temperature at 95% recovered	2.2 °C
Pentane and heavier volume %	1.72 %
Relative density at 15.6/15.6°C	0.59
Free water content	0

Table A.9. Boiler fuel products produced in base design.

Fuel	Amount
Syngas	15,000,000 Nm^3 gas/year
Fuel Oil No. 5	2,600 liquid m^3/year

Table A.10. Initial charge of requirements for base design.

Chemical/Catalyst	**Amount**
Ni/SiO_2 Catalyst	530,000 kg

Table A.11. Utility requirements for base design.

Utility	**Amount**
Boiler Feed Water	11,100,000,000 kg/year
Cooling Water	68,000,000 m^3/year
Electricity	34,000,000 kW
Refrigeration (Moderately Low Temp)	290,000,000 kg/year
Process Steam	12,000,000 kg/year
Natural Gas	2,300,000 N m^3/year

Table A.12. Equipment lettering system [47].

Letter	Definition
D	Process (Pressure) Vessels
E	Heat Exchangers
F	Storage Vessels
G	Gas Movers
L	Pumps
P	Package Units
Q	Furnaces
R	Reactors

Table A.13. Equipment number codes and corresponding definitions for base design.

Code	Definition
D-100 Series	Flash Drums
D-200 Series	Distillation Columns
D-300 Series	Reflux Drums
E-100 Series	Column Condensers
E-200 Series	Cooler Heat Exchangers
E-400 Series	Column Reboilers
E-500 Series	Heater Heat Exchangers
D-500 Series	Knockout Drums
G-100 Series	Compressors
L-100 Series	Pumps
P-100 Series	Refrigeration Unit
Q-100 Series	Boilers
R-100 Series	Reactors
1##	Unit Number
A	Equipment 1 for redundant equipment
B	Equipment 2 for redundant equipment

Table A.14. Equipment naming system using example number D-101 A.

Code	D	100 Series	101	A
Definition	Pressure Vessels	Flash Drum	First Unit	Equipment piece 1 of 2

Table A.15. Flash drum equipment list.

Equipment ID	Equipment Name/Description	Height (m)	Diameter (m)	Orientation	Pressure (kPa) Design Basis	Temperature (°C)	MOC
D-101	Flash 1	5.8	1.4	Vertical	690	215	Stainless Steel Clad
D-102	Flash 2	5.3	1.4	Vertical	140	150	Stainless Steel Clad
D-103	Flash 3	4.9	1.2	Vertical	1720	175	Carbon Steel
D-104	Flash 4	4.7	1.2	Vertical	100	170	Carbon Steel
D-105	Flash 5	3.8	0.9	Vertical	100	20	Carbon Steel
D-107	Acetic Flash 1	1.8	0.5	Horizontal	1380	215	Stainless Steel
D-108	Acetic Flash 2	3.4	0.8	Horizontal	210	60	Stainless Steel Clad
D-109	Flash 7	2.7	0.8	Vertical	170	100	Carbon Steel

Table A.16. Distillation column equipment list.

Equipment ID	Equipment Name/Description	Height (m)	Diameter (m)	Trays*	Feed Tray	Pressure (kPa)	Temperature (°C)	MOC: Body	MOC: Trays
D-201	Atmospheric Column	8.5	2.4	7	3	130	280	Stainless Steel Clad	Stainless Steel
D-202	Vacuum Column	20.4	2.9	20	5	28	330	Stainless Steel Clad	Stainless Steel
D-203	Hexane Splitter	11.9	1.5	12	4	170	140	Carbon Steel	Stainless Steel
D-204	Jet Diesel Cut	24.4	2.6	25	13	130	300	Carbon Steel	Stainless Steel
D-205	Naphtha-Jet Cut	27.4	1.4	30	7	130	210	Carbon Steel	Stainless Steel
D-206	Diesel-Fuel Oil Cut	37.8	2.7	40	28	140	530	Carbon Steel	Stainless Steel
D-207	Syngas Column	36.6	2.1	40	5	2800	170	Carbon Steel	Stainless Steel
D-210	Debutanizer	14	3.5	12	8	830	240	Carbon Steel	Stainless Steel
D-211	C5 Product Column	15.8	1.1	17	10	140	80	Carbon Steel	Stainless Steel

* Based on sieve trays at 80% efficiency

Table A.17. Reflux drum equipment list.

Equipment ID	Equipment Name/Description	Volume (m3)	Orientation	Length (m)	Diameter (m)	Temperature (°C)	Pressure (kPa)	Flow Rate (m3/min)	MOC
D-301	Atmospheric Column Reflux Drum	1.4	Horizontal	3	0.8	60	110	0.25	Stainless Steel Clad
D-302	Vacuum Column Reflux Drum	5.7	Horizontal	4.9	1.2	230	14	0.7	Stainless Steel Clad
D-303	Hexane Splitter Reflux Drum	2.4	Horizontal	3.7	0.9	34	150	0.2	Stainless Steel Clad
D-304	Jet-Diesel Cut Reflux Drum	2.4	Horizontal	3.7	0.9	40	103	0.3	Carbon Steel
D-305	Naphtha-Jet Cut Reflux Drum	1.4	Horizontal	3	0.8	120	110	0.2	Carbon Steel
D-306	Diesel-Fuel Oil Cut Reflux Drum	3.8	Horizontal	4.3	1.1	320	130	0.7	Carbon Steel
D-307	Syngas Column Reflux Drum	5.7	Horizontal	4.9	1.2	4	2675	0.4	Carbon Steel
D-308	Debutanizer Reflux Drum	14.8	Horizontal	6.7	1.7	70	810	1.3	Carbon Steel
D-309	C5 Product Reflux Drum	1.4	Horizontal	3	0.8	42	125	0.2	Carbon Steel
D-310	Acetic Acid Drum	0.1	Horizontal	1.2	0.3	93	210	0.01	Stainless Steel Clad

Table A.18. Heat exchanger equipment list.

Equipment ID	Equipment Name/Description	Area (m3)	Duty (kW)	Tube Inlet Temp (°C)	Tube Outlet Temp (°C)	Tube Pressure (kPa)	Tube MOC	Tube Fluid	Shell Inlet Temp (°C)	Shell Outlet Temp (°C)	Shell Pressure (kPa)	Shell MOC	Shell Fluid	Heat Transfer Coefficient (W/m^2-°C)
E-101 A/B	Atmospheric Column Condenser	660	2500	210	60	124	ss	C7-C12 fuel intermediates	55	205	4550	cs	Boiler feed water	852
E-102 A/B	Vacuum Column Condenser	120	5600	260	230	20	ss	C12-C30 fuel intermediates	55	205	4550	cs	Boiler feed water	341
E-103 A/B	Jet Diesel Cut Condenser	130	2800	230	40	117	ss	C8-C15 fuel intermediates	30	200	380	cs	Cooling Water	341
E-104 A/B	Syngas Condenser	90	590	15	4	2710	cs	Syngas	5	15	380	cs	Refrigerated Water	511
E-105 A/B	Naphtha Jet Condenser	27	1100	135	117	120	cs	C7-C9 fuel intermediates	30	100	380	cs	Cooling water	454
E-106 A/B	Debutanizer Condenser	57	880	74	70	830	cs	Butane	30	45	380	cs	Cooling Water	511
E-107 A/B	Diesel-Fuel Oil Cut Condenser	15	2200	340	320	145	cs	C16-C21 fuel intermediates	54	239	3340	cs	Medium pressure steam	852
E-108 A/B	Hexane Splitter Condenser	280	1400	67	34	165	cs	Light Ends	30	45	380	cs	Cooling water	483
E-109 A/B	C5 Product Condenser	240	790	46	42	130	cs	C5 Product	30	43	380	cs	Cooling Water	454
E-201 A/B	Post Cracking Cooler	320	14,000	430	230	1800	ss	C1-C50 fuel intermediates	20	310	140	cs	Soybean Oil	284
E-202 A/B	Flash 2 Cooler	250	2700	210	150	690	ss	C7-C50 fuel intermediates	55	205	4550	cs	Boiler feed water	284
E-204 A/B	Syngas Cooler	210	3200	155	32	3200	cs	Light Ends	30	100	380	cs	Cooling Water	511
E-205 A/B	Debutanizer Cooler	7	350	180	120	2750	cs	C4-C6 intermediates	30	100	380	cs	Cooling Water	511
E-207 A/B	Pre-Flash 5 Cooler	18	410	175	37	1720	ss	Syngas	30	130	380	cs	Cooling Water	511
E-208 A/B	Post Diesel Decarbox Cooler	33	2900	320	177	2200	cs	C1-C30 fuel intermediates	55	239	3340	cs	Medium pressure steam	852
E-209 A/B	Post Naphtha Decarbox Cooler	74	3500	320	93	2200	cs	C1-C12 fuel intermediates	55	239	3340	cs	Medium pressure steam	852
E-210 A/B	Interstage Cooler 1	30	670	137	35	413	ss	Light Ends	30	100	380	cs	Cooling Water	454
E-211 A/B	Interstage Cooler 2	18	820	180	35	1520	ss	Light Ends	30	150	380	cs	Cooling Water	454

(continued)

Table A.18. Cont.

Equipment ID	Equipment Name/Description	Area (m3)	Duty (kW)	Tube Inlet Temp (°C)	Tube Outlet Temp (°C)	Tube Pressure (kPa)	Tube MOC	Tube Fluid	Shell Inlet Temp (°C)	Shell Outlet Temp (°C)	Shell Pressure (kPa)	Shell MOC	Shell Fluid	Heat Transfer Coefficient (W/m^2-°C)
E-212 A/B	Naphtha Cooler	10	210	117	55	140	cs	Naphtha	30	100	380	cs	Cooling Water	454
E-213 A/B	Jet Cooler	44	970	160	55	130	cs	Jet Fuel	30	125	380	cs	Cooling Water	369
E-214 A/B	Diesel Cooler	130	3200	320	55	170	cs	Diesel Fuel No. 2	55	239	3340	cs	Medium pressure steam	852
E-215 A/B	Fuel Oil Cooler	2	82	400	55	210	cs	Fuel Oil No. 5	55	204	4550	cs	Boiler feed water	852
E-401 A/B	Atmospheric Column Reboiler	200	7300	400	330	4500	ss	High pressure steam	280	310	140	ss clad	C7-C50 fuel intermediates	539
E-402 A/B	Vacuum Column Reboiler	840	4400	400	330	4500	ss	High pressure steam	330	340	34	ss clad	Vacuum bottoms	341
E-403 A/B	Naphtha Jet Cut Reboiler	70	1300	239	239	3300	ss	Medium pressure steam	203	204	130	cs	C9-C12 fuel intermediates	539
E-404 A/B	Jet Diesel Cut Reboiler	170	3500	400	330	4500	ss	High pressure steam	290	300	140	cs	C16-C30 fuel intermediates	341
E-405 A/B	Syngas Column Reboiler	21	1100	239	239	3300	ss	Medium pressure steam	170	180	2800	cs	C4-C6 intermediates	852
E-406 A/B	Hexane Splitter Reboiler	64	2300	239	239	3300	ss	Medium pressure steam	140	160	170	cs	C7-C12 fuel intermediates	397
E-407 A/B	Debutanizer Reboiler	12	1000	239	239	3300	ss	Medium pressure steam	132	141	850	cs	C5-C6 intermediates	852
E-408A/B	C5 Product Reboiler	4	560	239	239	3300	ss	Medium pressure steam	81	84	144	cs	C6 Product	852
E-409 A/B	Diesel Fuel Oil Cut Reboiler	21	2400	435	370	6000	ss	Superheated Steam	398	40	170	cs	C22-C30 fuel intermediates	454
E-502 A/B	TTCT Preheat	290	6200	435	370	6000	ss	Superheated Steam	310	410	1900	ss clad	Soybean Oil	341
E-503 A/B	Naphtha Decarbox Heater	43	3800	400	330	4500	ss	High pressure steam	60	320	2400	ss clad	C6-C12 fuel intermediates	539
E-504 A/B	Diesel Decarbox Heater	40	1800	400	330	4500	ss	High pressure steam	230	320	2400	ss clad	C12-C30 fuel intermediates	483

Table A.19. Knockout drum equipment list.

Equipment ID	Equipment Name/Description	Volume (m3)	Orientation	Length (m)	Diameter (m)	Temperature (°C)	Pressure (kPa)	Flow Rate (m3/min)	MOC
D-505 A/B	Stage 1 Syngas Knockout Drum	53	Horizontal	3.9	1.3	24	103	1720	cs
D-506 A/B	Stage 2 Syngas Knockout Drum	8	Horizontal	2.1	0.7	52	400	510	cs
D-507 A/B	Stage 3 Syngas Knockout Drum	2	Horizontal	1.5	0.4	88	1500	140	cs

Table A.20. Compressor equipment list.

Equipment ID	Equipment Name/Description	Stages	Inlet Pressure (kPa)	Outlet Pressure (kPa)	Inlet Temp (°C)	Outlet Temp (°C)	Flow Rate (m3/min)	Power (kW)	MOC	Fluid
G-101 A/B	Flash 2 Compressor	Single	140	410	150	200	34	16	ss	C1-C8
G-103 A/B	Flash 5 Compressor	Single	103	240	170	220	60	15	cs	C3-C7
G-105 Stage 1	Light End Compressor	Three	103	413	24	137	1720	800	cs	C1-C6
G-105 Stage 2	Light End Compressor	Three	400	1520	35	180	1720	800	cs	C1-C6
G-105 Stage 3	Light End Compressor	Three	1500	3200	35	155	1720	800	cs	C1-C6

Table A.21. Pump equipment list.

Equipment ID	Equipment Name/Description	Power (kW)	Inlet Pressure (kPa)	Outlet Pressure (kPa)	Temperature (°C)	Fluid	MOC
L-102 A/B	PreCracking Pump	50	103	1930	310	Soybean Oil	ss
L-103 A/B	Pre Naphtha Decarbox	17	140	2400	60	C2-C12 fuel intermediates	ss
L-104 A/B	Atmospheric Reflux	1.6	89	140	60	C7-C12 fuel intermediates	ss
L-105 A/B	Atmospheric Bottoms	0.66	103	140	310	C13-C50 fuel intermediates	ss
L-106 A/B	Vacuum Column Bottom	4.3	34	140	330	Vacuum Bottoms	ss
L-107 A/B	Vacuum Bottoms	0.75	103	140	340	Vacuum Bottoms	ss
L-108 A/B	Vacuum Reflux	4.3	7	140	230	C12-C30 fuel intermediates	ss
L-109 A/B	PreDiesel Decarbox	29	140	2400	230	C12-C30 fuel intermediates	ss
L-110 A/B	PreJet-Diesel Cut Heat Pump	1.8	103	210	170	C8-C30 fuel intermediates	cs
L-111 A/B	Naphtha Product	0.71	103	170	55	Naphtha	Cs
L-112 A/B	Jet Diesel Cut Reflux	4.7	82	130	40	C8-C15 fuel intermediates	cs
L-113 A/B	Jet Diesel Cut Bottoms	0.87	105	170	300	C16-C30 fuel intermediates	cs
L-114 A/B	Diesel Fuel Oil Cut Reflux	6.8	110	170	320	C16-C21 fuel intermediates	cs
L-115 A/B	Diesel Fuel Oil Cut Bottoms	0.23	140	210	400	C22-C30 fuel intermediates	cs
L-116 A/B	Flash 5 Pump	0.05	103	170	21	C6-C9 fuel intermediates	ss
L-117 A/B	Hexane Splitter Reflux	2.2	140	170	160	C7-C12 fuel intermediates	cs
L-118 A/B	Jet Fuel Product	0.71	103	170	55	Jet Fuel	cs
L-119 A/B	Naphtha Jet Reflux	5	90	140	117	C7-C9 fuel intermediates	cs

(continued)

Table A.21. Cont.

Equipment ID	Equipment Name/Description	Power (kW)	Inlet Pressure (kPa)	Outlet Pressure (kPa)	Temperature (°C)	Fluid	MOC
L-120 A/B	Naphtha Jet Bottoms	0.69	97	193	204	C9-C12 fuel intermediates	Cs
L-121 A/ B	Debutanizer reflux	3.2	790	830	70	Butane	cs
L-124 A/B	C5 Bottoms	0.12	110	170	84	C5 Product	cs
L-125 A/B	C5 Reflux	2.9	103	140	42	C6 Product	cs
L-126 A/B	Hexane Splitter Reflux	0.75	131	140	34	Light ends	cs

Table A.22. Reactor equipment list.

Equipment ID	Equipment Name/Description	Diameter (m)	Length (m)	Tubes	Catalyst (m3)	Residence Time (hr)	Temperature (°C)	Pressure (kPa)	MOC
R-101	TTCR	6.1	12.2	10300	N/A	1.17	430	1800	cs/inconel
R-102 A/B	Naphtha Decarboxylation Reactor	2.7	17	N/A	220	3.2	320	2200	ss clad
R-103 A/B	Diesel Decarboxylation Reactor	3.4	19	N/A	310	4.8	320	2200	ss clad

Table. A.23 Drawing number codes and corresponding definitions for the base design.

Code	Definition
00	Entire Plant
01	Thermal Cracking Section
02	Purification Section
03	Decarboxylation Section
04	Trim Purification Section
05	Light End Processing
A	11x17” Drawing Size
007	Alternative Base Design Input/Output Diagram – Metric Units
008	Alternative Base Design Block Flow Diagram - Metric Units
009	Alternative Base Design Process Flow Diagram - Metric Units

Table A.24. Drawing naming system using example number 00-A-001/1.

Code	00	A	001	/1
Definition	Plant Section	Drawing Size	Drawing Type	Sheet

Table A.25. Broad cost estimate for the base design.

Equipment	Equipment Description	Number	Capacity/Size Specs	Purchased Equipment Cost Basis Date: Year 2004	 Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-101	Flash 1	1	Height: 5.8 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$ 11,750	$16,000	2.5	1	7	$110,000	$110,000
D-102	Flash 2	1	Height: 5.3 m Inside Diameter: 1.4 m Vertical Orientation MOC: Stainless Steel Clad	$11,500	$15,000	2.5	1	7	$110,000	$110,000
D-103	Flash 3	1	Height: 4.9 m Inside Diameter: 1.2m Vertical Orientation MOC: Carbon Steel	$11,000	$15,000	1	2	6	$89,000	$89,000
D-104	Flash 4	1	Height: 4.7 m Inside Diameter: 1.2 m Vertical Orientation MOC: Carbon Steel	$11,000	$15,000	1	1	4	$59,000	$59,000
D-105	Flash 5	1	Height: 3.8 m Inside Diameter: 0.9 m Vertical Orientation MOC: Carbon Steel	$10,000	$13,000	1	1	4	$54,000	$54,000
D-107	Acetic Flash 1	1	Length: 1.8 m Inside Diameter: 0.5 m Horizontal Orientation MOC: Stainless Steel	$1,500	$2,000	2.5	1.5	8	$16,000	$16,000
D-108	Acetic Flash 2	1	Length: 3.4 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$5,000	$6,700	2.5	1	7	$47,000	$47,000

(continued)

Table A.25. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-109	Flash 7	1	Height: 2.7 m Inside Diameter: 0.8 m Vertical Orientation MOC: Carbon Steel	$3,000	$4,000	1	1	4	$16,000	$16,000
D-201	Atmospheric Column	1	Height: 8.5 m Diameter: 2.4 m Trays: 7 Feed: Tray 3 MOC: Stainless Steel Clad	$40,000	$54,000	2.5	1	7	$380,000	$380,000
D-201 Trays	Atmospheric Column Trays	7	Diameter: 2.4 m MOC: Stainless Steel	From Quote	$2,500	1	1	1.2	$3,000	$21,000
D-202	Vacuum Colum	1	Height: 20.4 m Diameter: 2.9 m Trays: 20 Feed: Tray 5 MOC: Stainless Steel Clad	$70,000	$94,000	2.5	1	7	$660,000	$660,000
D-202 Trays	Vacuum Column Trays	20	Diameter: 2.9 m MOC: Stainless Steel	From Quote	$2,800	1	1	1.2	$2,800	$56,000
D-203	Hexane Splitter	1	Height: 11.9 m Diameter: 1.5 m Trays: 12 Feed: Tray 4 MOC: Carbon Steel	$25,000	$34,000	1	1	4	$130,000	$130,000
D-203 Trays	Hexane Splitter Trays	12	Diameter: 1.5 m MOC: Stainless Steel	From Quote	$1,900	1	1.15	1.2	$2,600	$32,000
D-204	Jet Diesel Cut	1	Height: 24.4 m Diameter: 2.6 m Trays: 25 Feed: Tray 13 MOC: Carbon Steel	$50,000	$67,000	1	1	4	$270,000	$270,000
D-204 Trays	Jet Diesel Cut Trays	25	Diameter: 2.6 m MOC: Stainless Steel	From Quote	$2,600	1	1.025	1.2	$3,200	$81,000

(continued)

Table A.25. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-205	Naphtha-Jet Cut	1	Height: 27.4 m Diameter: 1.4 m Trays: 30 Feed: Tray 7 MOC: Carbon Steel	$80,000	$110,000	1	1	4	$430,000	$430,000
D-205 Trays	Naphtha-Jet Cut Trays	30	Diameter: 1.4 m MOC: Stainless Steel	From Quote	$1,800	1	1	1.2	$2,200	$65,000
D-206	Diesel-Fuel Oil Cut	1	Height: 37.8 m Diameter: 2.7 m Trays: 40 Feed: Tray 28 MOC: Carbon Steel	$150,000	$200,000	1	1	4	$810,000	$810,000
D-206 Trays	Diesel-Fuel Oil Cut Trays	40	Diameter: 2.7 m MOC: Stainless Steel	From Quote	$2,800	1	1	1.2	$3,300	$130,000
D-207	Syngas Column	1	Height: 36.6 m Diameter: 2.1 m Trays: 40 Feed: Tray 5 MOC: Carbon Steel	$125,000	$170,000	1	3	8	$1,300,000	$1,300,000
D-207 Trays	Syngas Trays	40	Diameter: 2.1 m MOC: Stainless Steel	From Quote	$2,300	1	1	1.2	$2,800	$110,000
D-210	Debutanizer	1	Height: 14 m Diameter: 3.5 m Trays: 12 Feed: Tray 8 MOC: Carbon Steel	$70,000	$94,000	1	2	6	$560,000	$560,000
D-210 Trays	Debutanizer Trays	12	Diameter: 3.5 m MOC: Stainless Steel	From Quote	$3,100	1	1.18	1.2	$4,400	$53,000
D-211	C5 Product Column	1	Height: 15.8 m Diameter: 1.1 m Trays: 17 Feed: Tray 10 MOC: Carbon Steel	$30,000	$40,000	1	1	4	$160,000	$160,000

(continued)

Table A.25. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-211 Trays	C5 Product Column Trays	17	Diameter: 1.1 m MOC: Stainless Steel	From Quote	$1,500	1	1.08	1.2	$2,000	$34,000
D-301	Atmospheric Column Reflux Drum	1	Length: 3 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Stainless Steel Clad	$4,000	$5,400	2.5	1	4	$21,000	$21,000
D-302	Vacuum Column Reflux Drum	1	Length: 4.9 m Inside Diameter: 1.2 m Horizontal Orientation MOC: Stainless Steel Clad	$6,500	$8,700	2.5	1	4	$35,000	$35,000
D-303	Hexane Splitter Reflux Drum	1	Length: 3.7 m Inside Diameter: 0.9 m Horizontal Orientation MOC: Stainless Steel Clad	$5,000	$6,700	2.5	1	4	$27,000	$27,000
D-304	Jet-Diesel Cut Reflux Drum	1	Length: 3.7 m Inside Diameter: 0.9 m Horizontal Orientation MOC: Carbon Steel	$5,000	$6,700	1	1	3	$20,000	$20,000
D-305	Naphtha-Jet Cut Reflux Drum	1	Length: 3 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	$4,000	$5,400	1	1	3	$16,000	$16,000
D-306	Diesel-Fuel Oil Cut Reflux Drum	1	Length: 4.3 m Inside Diameter: 1.1 m Horizontal Orientation MOC: Carbon Steel	$6,000	$8,100	1	1	3	$24,000	$24,000
D-307	Syngas Column Reflux Drum	1	Length: 4.9 m Inside Diameter: 1.2 m Horizontal Orientation MOC: Carbon Steel	$6,500	$8,700	1	1	3	$26,000	$26,000
D-308	Debutanizer Reflux Drum	1	Length: 6.7 m Inside Diameter: 1.7 m Horizontal Orientation MOC: Carbon Steel	$8,000	$11,000	1	1	3	$32,000	$32,000

(continued)

Table A.25. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
D-309	C5 Product Reflux Drum	1	Length: 3 m Inside Diameter: 0.8 m Horizontal Orientation MOC: Carbon Steel	$5,000	$6,700	1	3	8	$54,000	$54,000
D-310	Acetic Acid Drum	1	Length: 1.2 m Inside Diameter: 0.3 m Horizontal Orientation MOC: Carbon Steel	$2,500	$3,400	4	1	5	$17,000	$17,000
E-101 A/B	Atmospheric Column Condenser	2	Surface Area: 660 m2 Heat Duty: 2500 kW MOC (shell/tube): cs/ss	$55,000	$74,000	1.7	1	4	$130,000	$250,000
E-102 A/B	Vacuum Column Condenser	2	Surface Area: 120 m2 Heat Duty: 5600 kW MOC (shell/tube): cs/ss	$14,000	$19,000	1.7	1	4	$75,000	$150,000
E-103 A/B	Jet Diesel Cut Condenser	2	Surface Area: 130 m2 Heat Duty: 2800 kW MOC (shell/tube): cs/ss	$15,000	$20,000	1.7	1	4	$81,000	$160,000
E-104 A/B	Syngas Condenser	2	Surface Area: 90 m2 Heat Duty: 590 kW MOC (shell/tube): cs/cs	$12,500	$17,000	1	1	3.2	$54,000	$110,000
E-105 A/B	Naphtha Jet Condenser	2	Surface Area: 27 m2 Heat Duty: 1100 kW MOC (shell/tube): cs/cs	$8,000	$11,000	1	1.1	3.2	$34,000	$69,000
E-106 A/B	Debutanizer Condenser	2	Surface Area: 57 m2 Heat Duty: 880 kW MOC (shell/tube): cs/cs	$11,000	$15,000	1	1	3.2	$47,000	$95,000
E-107 A/B	Diesel-Fuel Oil Cut Condenser	2	Surface Area: 15 m2 Heat Duty: 2200 kW MOC (shell/tube): cs/cs	$4,000	$5,400	1	1	3.2	$17,000	$34,000
E-108 A/B	Hexane Splitter Condenser	2	Surface Area: 280 m2 Heat Duty: 1400 kW MOC (shell/tube): cs/cs	$27,500	$37,000	1	1	3.2	$120,000	$240,000
E-109 A/B	C5 Product Condenser	2	Surface Area: 240 m2 Heat Duty: 790 kW MOC (shell/tube): cs/cs	$27,500	$37,000	1	1	3.2	$120,000	$240,000

(continued)

Table A.25. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-201 A/B	Post Cracking Cooler	2	Surface Area: 320 m2 Heat Duty: 14,000 kW MOC (shell/tube): cs/ss	$30,000	$40,000	1.7	1	4	$160,000	$320,000
E-202 A/B	Flash 2 Cooler	2	Surface Area: 250 m2 Heat Duty: 2700 kW MOC (shell/tube): cs/ss	$25,000	$34,000	1.7	1.25	4	$130,000	$270,000
E-204 A/B	Syngas Cooler	2	Surface Area: 210 m2 Heat Duty: 3200 kW MOC (shell/tube): cs/cs	$25,000	$34,000	1	1.1	3.25	$110,000	$220,000
E-205 A/B	Debutanizer Cooler	2	Surface Area: 7 m2 Heat Duty: 350 kW MOC (shell/tube): cs/cs	$3,500	$4,700	1	1	3.2	$15,000	$30,000
E-207 A/B	Pre-Flash 5 Cooler	2	Surface Area: 18 m2 Heat Duty: 410 kW MOC (shell/tube): cs/ss	$6,000	$8,100	1.7	1	4	$32,000	$64,000
E-208 A/B	Post Diesel Decarbox Cooler	2	Surface Area: 33 m2 Heat Duty: 2900 kW MOC (shell/tube): cs/cs	$8,000	$11,000	1	1	3.2	$34,000	$69,000
E-209 A/B	Post Naphtha Decarbox Cooler	2	Surface Area: 74 m2 Heat Duty: 3500 kW MOC (shell/tube): cs/cs	$14,000	$19,000	1	1	3.2	$60,000	$120,000
E-210 A/B	Interstage Cooler 1	2	Surface Area: 30 m2 Heat Duty: 670 kW MOC (shell/tube): cs/ss	$8,000	$11,000	1.7	1	4	$43,000	$86,000
E-211 A/B	Interstage Cooler 2	2	Surface Area: 18 m2 Heat Duty: 820 kW MOC (shell/tube): cs/ss	$6,000	$8,100	1.7	1	4	$32,000	$64,000
E-212 A/B	Naphtha Cooler	2	Surface Area: 10 m2 Heat Duty: 210 kW MOC (shell/tube): cs/cs	$5,000	$6,700	1	1	3.2	$21,000	$43,000
E-213 A/B	Jet Cooler	2	Surface Area: 44 m2 Heat Duty: 970 kW MOC (shell/tube): cs/cs	$10,000	$13,000	1	1	3.2	$43,000	$86,000
E-214 A/B	Diesel Cooler	2	Surface Area: 130 m2 Heat Duty: 3200 kW MOC (shell/tube): cs/cs	$14,000	$19,000	1	1	3.2	$60,000	$120,000

(continued)

Table A.25. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-215 A/B	Fuel Oil Cooler	2	Surface Area: 2 m2 Heat Duty: 82 kW MOC (shell/tube): cs/cs	$2,500	$3,400	1	1	3.2	$11,000	$21,000
E-401 A/B	Atmospheric Column Reboiler	2	Surface Area: 200 m2 Heat Duty: 7300 kW MOC (shell/tube): ssclad/ss	$22,500	$30,000	3	1.1	6	$180,000	$360,000
E-402 A/B	Vacuum Column Reboiler	2	Surface Area: 840 m2 Heat Duty: 4400 kW MOC (shell/tube): ssclad/ss	$60,000	$81,000	3	1.1	6	$480,000	$970,000
E-403 A/B	Naphtha Jet Cut Reboiler	2	Surface Area: 70 m2 Heat Duty: 1300 kW MOC (shell/tube): cs/ss	$11,000	$15,000	1.7	1	4	$59,000	$120,000
E-404 A/B	Jet Diesel Cut Reboiler	2	Surface Area: 170 m2 Heat Duty: 3500 kW MOC (shell/tube): cs/ss	$20,000	$27,000	1.7	1.1	4.5	$120,000	$240,000
E-405 A/B	Syngas Column Reboiler	2	Surface Area: 21 m2 Heat Duty: 1100 kW MOC (shell/tube): cs/ss	$8,000	$11,000	1.7	1.1	4.5	$48,000	$97,000
E-406 A/B	Hexane Splitter Reboiler	2	Surface Area: 64 m2 Heat Duty: 2300 kW MOC (shell/tube): cs/ss	$12,000	$16,000	1.7	1.1	4.5	$73,000	$150,000
E-407 A/B	Debutanizer Reboiler	2	Surface Area: 12 m2 Heat Duty: 1000 kW MOC (shell/tube): cs/ss	$5,000	$6,700	1.7	1.1	4.5	$30,000	$60,000
E-408A/B	C5 Product Reboiler	2	Surface Area: 4 m2 Heat Duty: 560 kW MOC (shell/tube): cs/ss	$3,000	$4,000	1.7	1	4	$16,000	$32,000
E-409 A/B	Diesel Fuel Oil Cut Reboiler	2	Surface Area: 210 m2 Heat Duty: 2400 kW MOC (shell/tube): cs/ss	$25,000	$34,000	1.7	1.1	4.5	$150,000	$300,000
E-502	TTCT Preheat	2	Surface Area: 290 m2 Heat Duty: 6200 kW MOC (shell/tube): ss/ss	$27,500	$37,000	3	1.25	7	$260,000	$520,000

(continued)

Table A.25. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
E-503 A/B	Naphtha Decarbox Heater	2	Surface Area: 43 m2 Heat Duty: 3800 kW MOC (shell/tube): cs/ssclad	$10,000	$13,000	1.7	1.1	4.5	$60,000	$120,000
E-504 A/B	Diesel Decarbox Heater	2	Surface Area: 40 m2 Heat Duty: 1800 kW MOC (shell/tube): cs/ssclad	$10,000	$13,000	1.7	1.1	4.5	$60,000	$120,000
E-505 A/B	Pre Jet Diesel Cut Heat	2	Surface Area: 22 m2 Heat Duty: 530 kW MOC (shell/tube): cs/cs	$6,000	$8,100	1	1	3.2	$26,000	$52,000
D-505 A/B	Stage 1 Syngas Knockout Drum	2	Height: 3.9 m Inside Diameter: 1.3 m Horizontal Orientation MOC: Carbon Steel	$10,250	$14,000	1	1	4	$55,000	$110,000
D-506 A/B	Stage 2 Syngas Knockout Drum	2	Height: 2.1 m Inside Diameter: 0.7 m Horizontal Orientation MOC: Carbon Steel	$4,500	$6,000	1	1	4	$24,000	$48,000
D-507 A/B	Stage 3 Syngas Knockout Drum	2	Height: 1.5 m Inside Diameter: 0.4 m Horizontal Orientation MOC: Carbon Steel	$3,000	$4,000	1	1	4	$16,000	$32,000
G-101 A/B	Flash 2 Compressor	2	Power: 16 kW Number of Stages: 1 MOC: Stainless Steel	From Quote	$18,000	1	1	2.52	$46,000	$91,000
G-103 A/B	Flash 5 Compressor	2	Power: 15 kW Number of Stages: 1 MOC: Carbon Steel	From Quote	$16,000	1	1	2.5	$41,000	$81,000
G-105	Light End Compressor	1	Power: 2300 kW Number of Stages: 3 MOC: Carbon Steel	From Quote	$2,500,000	1	1	2.5	$6,300,000	$6,300,000

(continued)

Table A.25. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-102 A/B	PreCracking Pump 2	2	Power: 50 kW Suction Pressure: 210 kPa MOC: Stainless Steel	$11,000	$15,000	1.9	1	4.5	$66,000	$130,000
L-103 A/B	Pre Naphtha Decarbox	2	Power: 17 kW Suction Pressure: 120 kPa MOC: Stainless Steel	$10,000	$13,000	1.9	1	4.5	$60,000	$120,000
L-104 A/B	Atmospheric Reflux	2	Power: 1.6 kW Suction Pressure: 100 kPa MOC: Stainless Steel	$4,000	$5,400	1.9	1	3.2	$17,000	$34,000
L-105 A/B	Atmospheric Bottoms	2	Power: 660 W Suction Pressure: 100 kPa MOC: Stainless Steel	$3,750	$5,000	1.9	1	3.2	$16,000	$32,000
L-106 A/B	Vacuum Column Bottom	2	Power: 4.3 kW Suction Pressure: 33 kPa MOC: Stainless Steel	$5,000	$6,700	1.9	1	3.2	$21,000	$43,000
L-107 A/B	Vacuum Bottoms	2	Power: 750 W Suction Pressure: 100 kPa MOC: Stainless Steel	$3,800	$5,100	1.9	1	3.2	$16,000	$33,000
L-108 A/B	Vacuum Reflux	2	Power: 4.3 kW Suction Pressure: 100 kPa MOC: Stainless Steel	$5,000	$6,700	1.9	1	3.2	$21,000	$43,000
L-109 A/B	PreDiesel Decarbox	2	Power: 29 kW Suction Pressure: 120 kPa MOC: Stainless Steel	$10,750	$14,000	1.9	1	4.5	$65,000	$130,000
L-110 A/B	PreJet-Diesel Cut Heat Pump	2	Power: 1.8 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$4,000	$5,400	1.4	1	3.2	$17,000	$34,000
L-111 A/B	Naphtha Product	2	Power: 500 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,750	$5,000	1.4	1	3.2	$16,000	$32,000
L-112 A/B	Jet Diesel Cut Reflux	2	Power: 4.7 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$5,250	$7,100	1.4	1	3.2	$23,000	$45,000

(continued)

Table A.25. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factor, Fm	Pressure or other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-113 A/B	Jet Diesel Cut Bottoms	2	Power: 870 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,800	$5,100	1.4	1	3.2	$16,000	$33,000
L-114 A/B	Diesel Fuel Oil Cut Reflux	2	Power: 6.8 kW Suction Pressure: 100 kPa MOC: Stainless Steel	$8,500	$11,000	1.9	1	3.2	$37,000	$73,000
L-115 A/B	Diesel Fuel Oil Cut Bottoms	2	Power: 230 W Suction Pressure: 140 kPa MOC: Stainless Steel	$3,400	$4,600	1.9	1	3.2	$15,000	$29,000
L-116 A/B	Flash 5 Pump	2	Power: 52 W Suction Pressure: 100 kPa MOC: Stainless Steel	$2,750	$3,700	1.9	1	3.2	$12,000	$24,000
L-117 A/B	Hexane Splitter Reflux	2	Power: 2.2 kW Suction Pressure: 140 kPa MOC: Carbon Steel	$4,250	$5,700	1.4	1	3.2	$18,000	$37,000
L-118 A/B	Jet Fuel Product	2	Power: 710 W Suction Pressure: 140 kPa MOC: Carbon Steel	$4,000	$5,400	1.4	1	3.2	$17,000	$34,000
L-119 A/B	Naphtha Jet Reflux	2	Power: 5.0 kW Suction Pressure: 110 kPa MOC: Carbon Steel	$5,250	$7,100	1.4	1	3.2	$23,000	$45,000
L-120 A/B	Naphtha Jet Bottoms	2	Power: 690 W Suction Pressure: 100 kPa MOC: Carbon Steel	$3,800	$5,100	1.4	1	3.2	$16,000	$33,000
L-121 A/ B	Debutanizer reflux	2	Power: 3.2 kW Suction Pressure: 830 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	3.2	$21,000	$43,000
L-124 A/B	C5 Bottoms	2	Power: 120 W Suction Pressure: 120 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	3.2	$13,000	$26,000
L-125 A/B	C5 Reflux	2	Power: 2.9 kW Suction Pressure: 100 kPa MOC: Carbon Steel	$5,000	$6,700	1.4	1	3.2	$21,000	$43,000

(continued)

Table A.25. Broad cost estimate for base design cont.

Equipment	Equipment Description	Number	Capacity/Size Specs	Basis Date: Year 2004	Target Year (2016)	Material Factors, Fm	Pressure and other Factors, Fp	Base bare module factor, Fbm	Base bare module cost, Cbm	Total
L-126 A/B	Hexane Splitter Reflux	2	Power: 750 W Suction Pressure: 130 kPa MOC: Carbon Steel	$4,000	$5,400	1.4	1	3.2	$17,000	$34,000
L-127 A/B	Syngas Column Reflux Drum	2	Power: 750 W Suction Pressure: 2700 kPa MOC: Carbon Steel	$3,000	$4,000	1.4	1	3.2	$13,000	$26,000
P-101	Refrigeration System	1	Load: 820-890 metric tons Power: 200 Volts	From Quote	$1,800,000	1	1	3.2	$5,900,000	$5,900,000
Q-101	TTCR Boiler	1	Duty: 28,000 kW	From Quote	$1,300,000	1	1	3.2	$4,200,000	$4,200,000
Q-102	High Pressure Steam Boiler	1	Duty: 12,000 kW	From Quote	$760,000	1	1	3.2	$2,400,000	$2,400,000
R-101	TTCR	1	Diameter: 6.1 m Length: 12.2 m Tubes: 10300 MOC: cs/inconel	From Quote	$30,000,000	0.7	1	3.2	$21,000,000	$21,000,000
R-102 A/B	Naphtha Decarboxylation Reactor	2	Diameter: 2.7 m Length: 17 m MOC: Stainless Steel Clad	From Quote	$840,000	1	1	3.2	$2,700,000	$5,400,000
R-103 A/B	Diesel Decarboxylation Reactor	2	Diameter: 3.4 m Length: 19 m MOC: Stainless Steel Clad	From Quote	$1,000,000	1	1	3.2	$3,300,000	$6,700,000

Total Bare Module Cost	CTBM	$ 65,000,000
Contingency and Fee	CTBM*0.18	$ 12,000,000
Total Module Cost	CTM	$77,000,000
Auxiliary Facilities	CTM*0.2	$ 15,000,000
Fixed Capital Investment	FCI	$ 93,000,000
Working Capital	FCI*0.15	$ 14,000,000
Chemicals & Catalysts		$ 19,000,000
Total Capital Investment	TCI	$ 130,000,000

Notes: Actual numbers may be off due to rounding

Table A.26. Operating expense summary for base design.

Year	Chemicals & Catalysts	Operating Labor	Maintenance	Utilities	Yearly Total
1	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000
2	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000
3	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000
4	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000
5	$ 19,000,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 35,000,000
6	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000
7	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000
8	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000
9	$ 14,000,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 35,000,000
10	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000
11	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000
12	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000
13	$ 19,000,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 35,000,000
14	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000
15	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000
16	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000
17	$ 19,000,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 35,000,000
18	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000
19	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000
20	$ 750,000	$ 2,200,000	$ 5,600,000	$ 8,700,000	$ 17,000,000

Notes: Actual numbers may be off due to rounding

Table A.27. Cash flow sheet for base design.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR	Present Value @ DCFROR
-1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (46,000)	$ (46,000)	$ (52,000)	$ (46,000)
0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (79,000)	$ (79,000)	$ (79,000)	$ (79,000)
1	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ (15,000)	$ (190,000)	$ (78,000)	$ -	$ (96,000)	$ (85,000)	$ (96,000)
2	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ (13,000)	$ (190,000)	$ (77,000)	$ -	$ (96,000)	$ (77,000)	$ (96,000)
3	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ (11,000)	$ (180,000)	$ (76,000)	$ -	$ (97,000)	$ (69,000)	$ (97,000)
4	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ (10,000)	$ (180,000)	$ (76,000)	$ -	$ (97,000)	$ (62,000)	$ (97,000)
5	$ 140,000	$ 300,000	$ 35,000	$ (190,000)	$ (8,900)	$ (200,000)	$ (83,000)	$ -	$ (110,000)	$ (62,000)	$ (110,000)
6	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ (7,900)	$ (180,000)	$ (75,000)	$ -	$ (98,000)	$ (50,000)	$ (98,000)
7	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ (6,900)	$ (180,000)	$ (75,000)	$ -	$ (99,000)	$ (45,000)	$ (99,000)
8	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ (6,100)	$ (180,000)	$ (74,000)	$ -	$ (99,000)	$ (40,000)	$ (99,000)
9	$ 140,000	$ 300,000	$ 35,000	$ (190,000)	$ (5,400)	$ (200,000)	$ (81,000)	$ -	$ (110,000)	$ (40,000)	$ (110,000)
10	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ (5,100)	$ (180,000)	$ (74,000)	$ -	$ (100,000)	$ (32,000)	$ (100,000)
11	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ (5,100)	$ (180,000)	$ (74,000)	$ -	$ (100,000)	$ (29,000)	$ (100,000)
12	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ (5,100)	$ (180,000)	$ (74,000)	$ -	$ (100,000)	$ (26,000)	$ (100,000)
13	$ 140,000	$ 300,000	$ 35,000	$ (190,000)	$ (5,100)	$ (200,000)	$ (81,000)	$ -	$ (110,000)	$ (25,000)	$ (110,000)
14	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ (5,100)	$ (180,000)	$ (74,000)	$ -	$ (100,000)	$ (20,000)	$ (100,000)
15	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ (5,100)	$ (180,000)	$ (74,000)	$ -	$ (100,000)	$ (18,000)	$ (100,000)
16	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ (5,100)	$ (180,000)	$ (74,000)	$ -	$ (100,000)	$ (16,000)	$ (100,000)
17	$ 140,000	$ 300,000	$ 35,000	$ (190,000)	$ (5,100)	$ (200,000)	$ (81,000)	$ -	$ (110,000)	$ (16,000)	$ (110,000)
18	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ -	$ (170,000)	$ (72,000)	$ -	$ (100,000)	$ (13,000)	$ (100,000)
19	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ -	$ (170,000)	$ (72,000)	$ -	$ (100,000)	$ (12,000)	$ (100,000)
20	$ 140,000	$ 300,000	$ 17,000	$ (170,000)	$ -	$ (170,000)	$ (72,000)	$ 15,000	$ (87,000)	$ (9,000)	$ (87,000)
									NPV@HR	$ (880,000)	$ (2,100,000)
									DCFROR	0%	
									HR	12%	

Notes: Dollar values are in thousands

Actual numbers may be off due to rounding

Numbers in parenthesis represent negative numbers

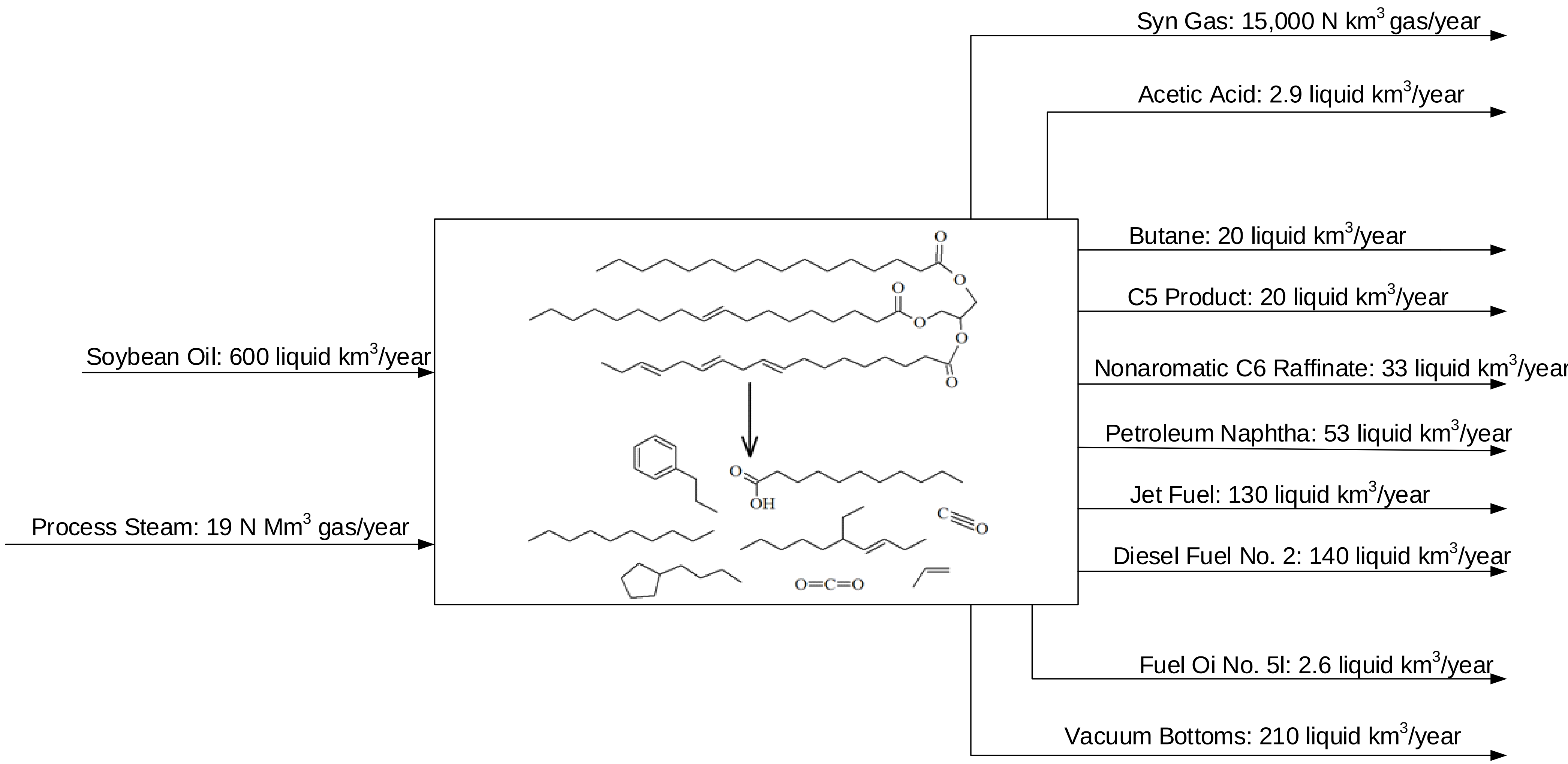
Table A.28. Cash flow sheet for base design and a soybean oil cost of $0.04/kg.

Year	Revenues	Raw Mat. Cost	Manuf. Cost	Gross Profit	Depreciation	Taxable Profit	Income Tax	Nontaxable Charges	Net Profit	Present Value @ HR
-1	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (46,000)	$ (46,000)	$ (52,000)
0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ (79,000)	$ (79,000)	$ (79,000)
1	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ (15,000)	$ 12,000	$ (4,900)	$ -	$ 22,000	$ 19,000
2	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ (13,000)	$ 14,000	$ (5,600)	$ -	$ 21,000	$ 17,000
3	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ (11,000)	$ 15,000	$ (6,300)	$ -	$ 20,000	$ 14,000
4	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ (10,000)	$ 16,000	$ (6,800)	$ -	$ 20,000	$ 13,000
5	$ 140,000	$ 100,000	$ 35,000	$ 8,700	$ (8,900)	$ (250)	$ 100	$ -	$ 8,800	$ 5,000
6	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ (7,900)	$ 19,000	$ (7,700)	$ -	$ 19,000	$ 9,500
7	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ (6,900)	$ 20,000	$ (8,100)	$ -	$ 18,000	$ 8,400
8	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ (6,100)	$ 20,000	$ (8,500)	$ -	$ 18,000	$ 7,300
9	$ 140,000	$ 100,000	$ 35,000	$ 8,700	$ (5,400)	$ 3,300	$ (1,300)	$ -	$ 7,300	$ 2,600
10	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ (5,100)	$ 22,000	$ (8,900)	$ -	$ 18,000	$ 5,700
11	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ (5,100)	$ 22,000	$ (8,900)	$ -	$ 18,000	$ 5,100
12	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ (5,100)	$ 22,000	$ (8,900)	$ -	$ 18,000	$ 4,500
13	$ 140,000	$ 100,000	$ 35,000	$ 8,700	$ (5,100)	$ 3,600	$ (1,500)	$ -	$ 7,200	$ 1,600
14	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ (5,100)	$ 22,000	$ (8,900)	$ -	$ 18,000	$ 3,600
15	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ (5,100)	$ 22,000	$ (8,900)	$ -	$ 18,000	$ 3,200
16	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ (5,100)	$ 22,000	$ (8,900)	$ -	$ 18,000	$ 2,900
17	$ 140,000	$ 100,000	$ 35,000	$ 8,700	$ (5,100)	$ 3,600	$ (1,500)	$ -	$ 7,200	$ 1,000
18	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ -	$ 27,000	$ (11,000)	$ -	$ 16,000	$ 2,000
19	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ -	$ 27,000	$ (11,000)	$ -	$ 16,000	$ 1,800
20	$ 140,000	$ 100,000	$ 17,000	$ 27,000	$ -	$ 27,000	$ (11,000)	$ 15,000	$ 31,000	$ 3,200
									NPV@HR	$ 0
									DCFROR	12%
									HR	12%

Notes: Dollar values are in thousands

Actual numbers may be off due to rounding

Numbers in parenthesis represent negative numbers



Notes

1. Material balance may be off due to rounding errors.

Special Symbols / Nomenclature

Reference Drawings:

Block Flow Diagram
00-A-008

Process Flow Diagram
00-A-009

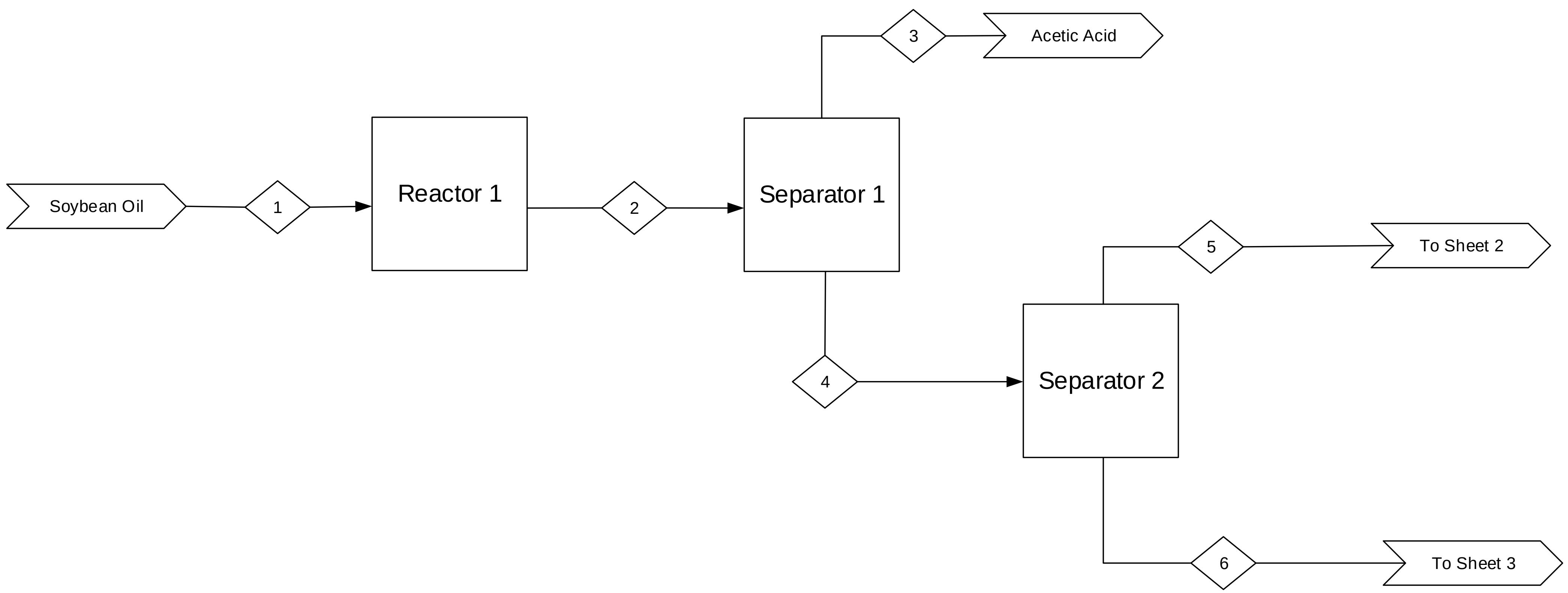
Drawing Type

Input/Output Diagram

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Alternative Base Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 12/21/16	00-A-007	0



Component/Stream (kg/min)	1	2	3	4	5	6
Soybean Oil	1000	0	0	0	0	0
Acetic Acid	0	0	5	0	0	0
C1-C50	0	1000	0	1000	0	0
C1-C12	0	0	0	0	440	0
C12-C50	0	0	0	0	0	550
Total	1000	1000	5	1000	440	550

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 1: Crack incoming TG oil into fuel intermediates

Separator 1:Separate aqueous acetic acid from organic crackate

Separator 2: Separate the naphtha range fuel intermediates from the diesel range fuel intermediates

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-007

Process Flow Diagram
00-A-009

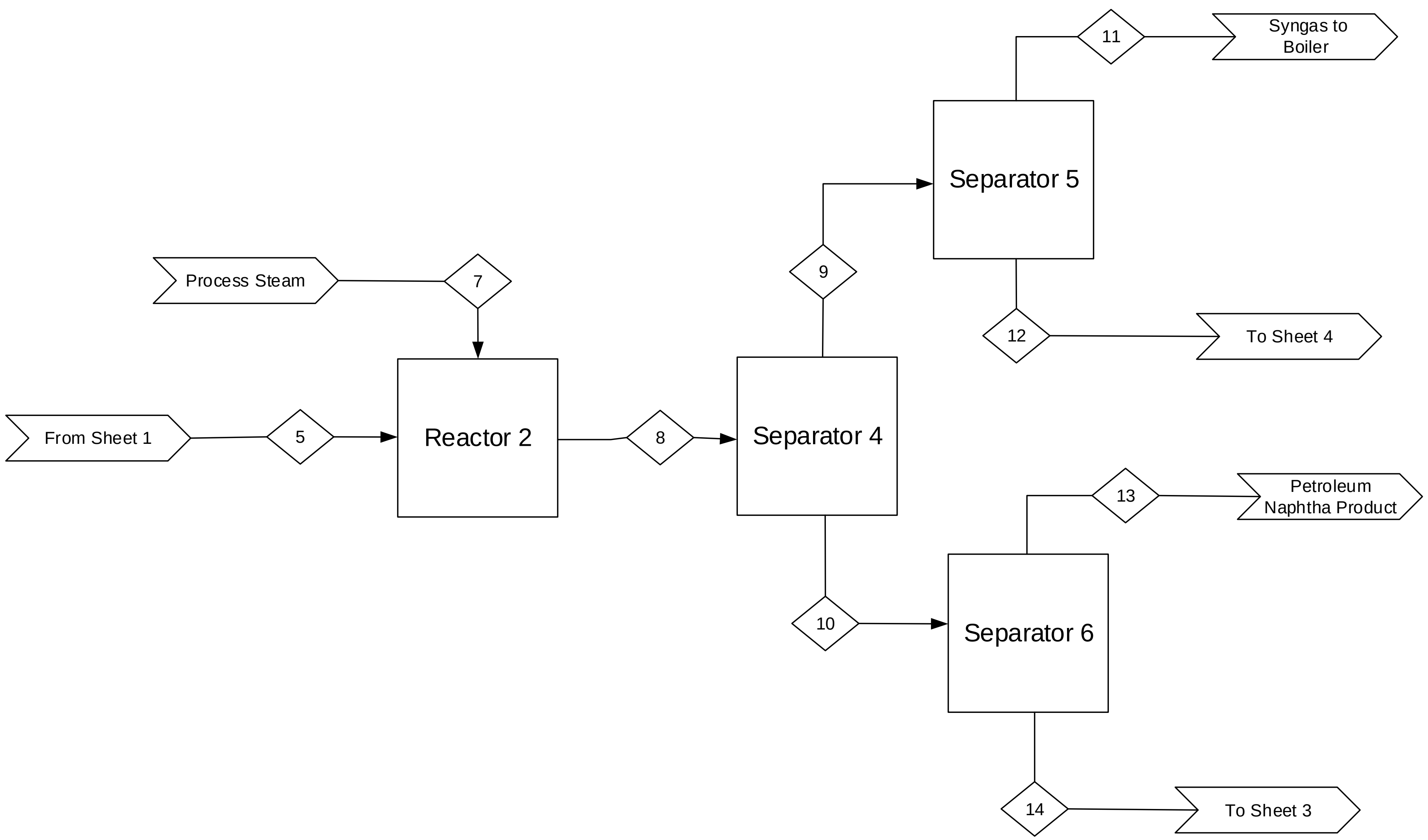
Drawing Type

Block Flow Diagram

Title

Biorefinery Alternative Base Design – Thermal Cracking and Purification Sections

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-21-16	00-A-008/1	0



Component/Stream (kg/min)	5	7	8	9	10	11	12	13	14
C1-C12	440	0	440	0	0	0	0	0	0
Steam	0	7	0	0	0	0	0	0	0
C1-C6	0	0	0	250	0	0	0	0	0
C1-C3	0	0	0	0	0	160	0	0	0
C4-C6	0	0	0	0	0	0	86	0	0
C7-C10	0	0	0	0	0	0	0	68	0
C11-C13	0	0	0	0	0	0	0	0	120
C7-C13	0	0	0	0	190	0	0	0	0
Total	440	7	440	250	190	160	86	68	120

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 2: Reacts the carboxylic acids and alkenes to produce hydrocarbons.

Separator 4: Removes light ends from naphtha range fuel intermediates.

Separator 5: Removes syngas from C4-C6 byproducts.

Separator 6: Separates petroleum naphtha product from jet fuel range fuel intermediates.

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

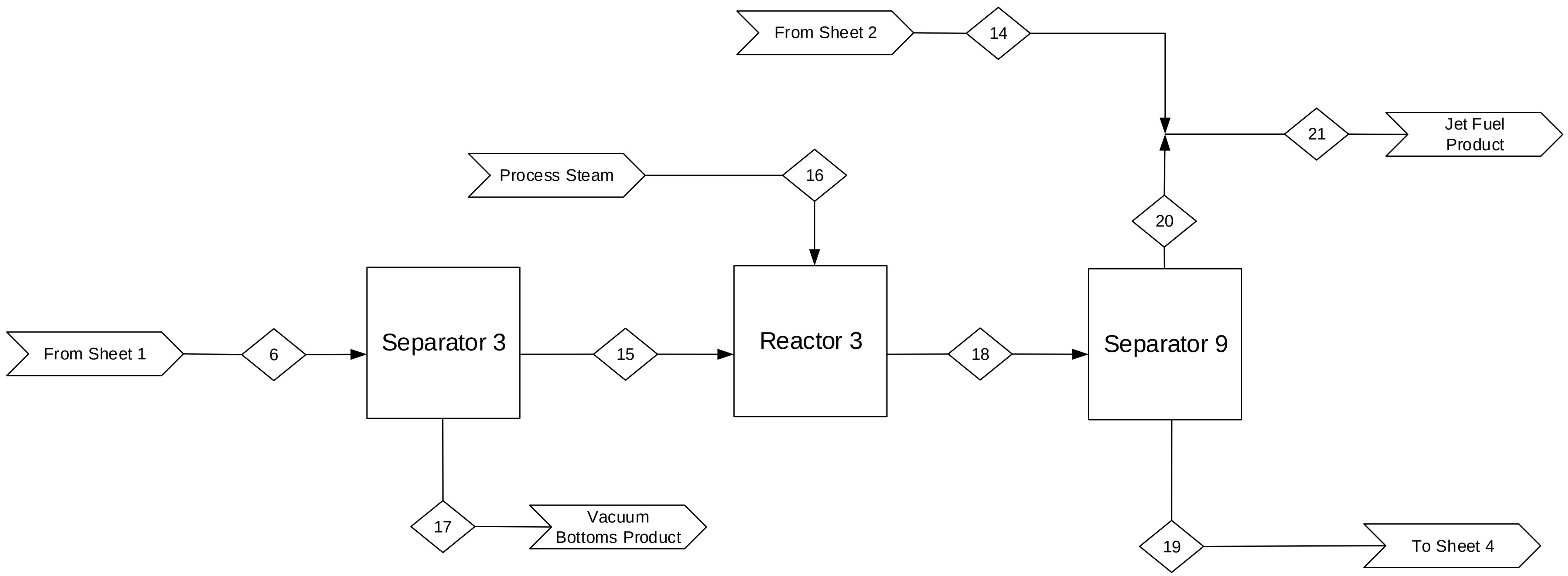
Input/Output Diagram
00-A-007

Process Flow Diagram
00-A-009

Drawing Type
Block Flow Diagram

Title
Biorefinery Alternative Base Design – Decarboxylation and Trim Purification Sections

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-21-16	00-A-008/2	0



Component/Stream (kg/min)	6	14	15	16	17	18	19	20	21
Steam	0	0	0	9	0	0	0	0	0
C12-C50	550	0	0	0	0	0	0	0	0
C30-C50	0	0	0	0	280	0	0	0	0
C12-C30	0	0	280	0	0	290	0	0	0
C13-C15	0	0	0	0	0	0	0	73	0
C11-C13	0	120	0	0	0	0	0	0	0
C11-C15	0	0	0	0	0	0	0	0	200
C15-C30	0	0	0	0	0	0	220	0	0
Total	550	120	280	9	280	290	220	73	200

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in kg/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

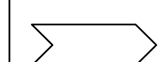
6. Assume 100% separation in separators.

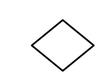
7. Reactor 3: Reacts carboxylic acids and alkenes to produce hydrocarbons.

Separator 3: Separates diesel fuel range intermediates from the vacuum bottoms byproduct.

Separator 9: Separates jet fuel range fuel intermediates from diesel fuel range intermediates.

Special Symbols / Nomenclature


Input/Output


Stream Indicator

Reference Drawings:
Input/Output Diagram
00-A-007

Process Flow Diagram
00-A-009

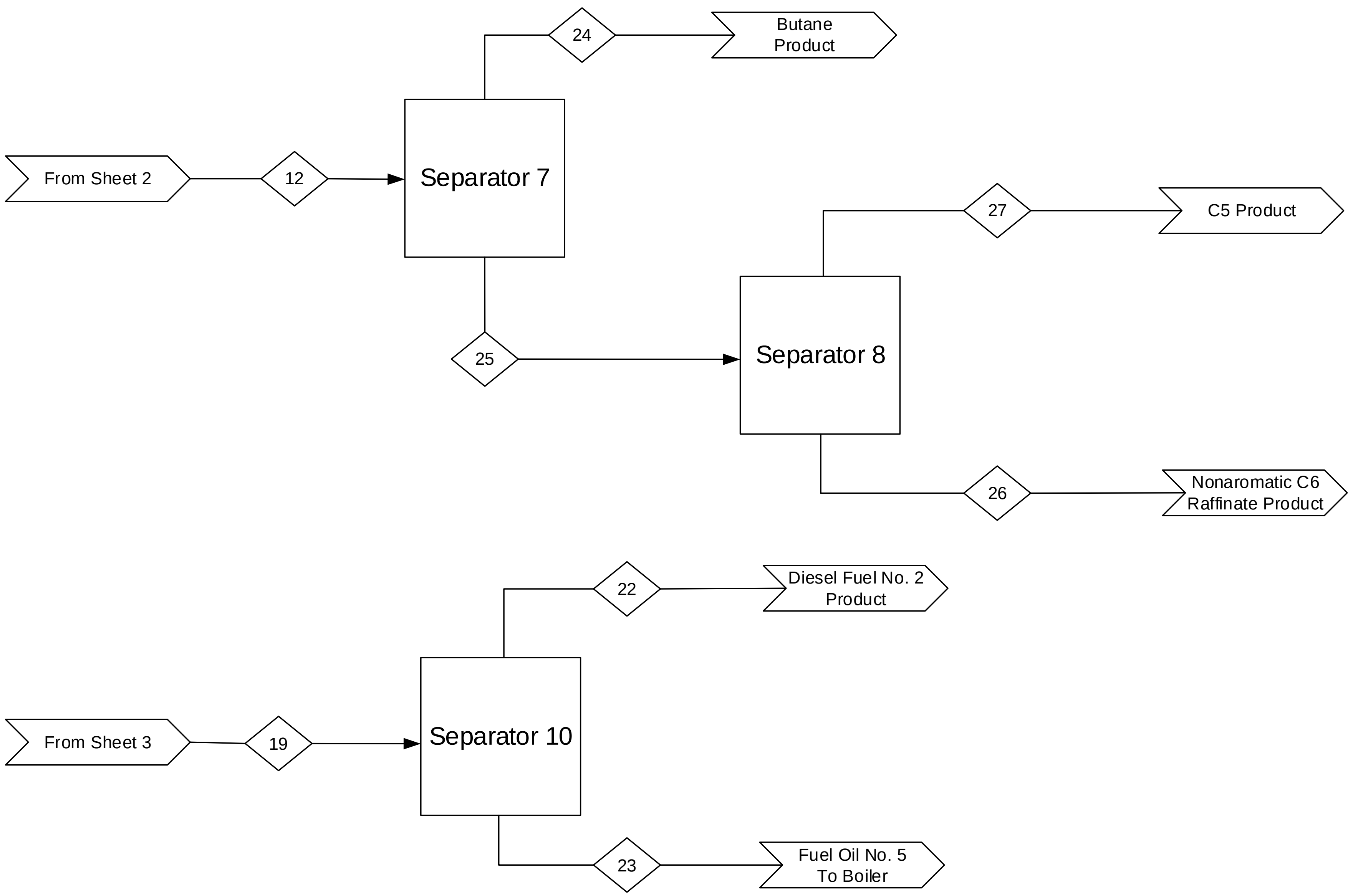
Drawing Type

Block Flow Diagram

Title

Biorefinery Alternative Base Design – Decarboxylation and Trim Purification Sections

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-21-16	00-A-008/3	0



Component/Stream (kg/min)	12	19	22	23	24	25	26	27
C4-C6	86	0	0	0	0	0	0	0
C4	0	0	0	0	23	0	0	0
C5-C6	0	0	0	0	0	64	0	0
C5	0	0	0	0	0	0	0	23
C6	0	0	0	0	0	0	41	0
C15-C22	0	0	210	0	0	0	0	0
C23-C30	0	0	0	6	0	0	0	0
C15-C30	0	220	0	0	0	0	0	0
Total	86	220	210	6	23	64	41	23

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

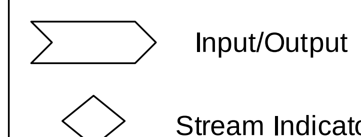
6. Assume 100% separation in separators.

7. Separator 7: Separates butane byproduct from C5 and C6 byproducts.

Separator 8: Separates C5 byproduct from the C6 byproduct.

Separator 10: Separates the diesel fuel no. 2 product from the fuel oi no 5. product.

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagram
00-A-007

Process Flow Diagram
00-A-009

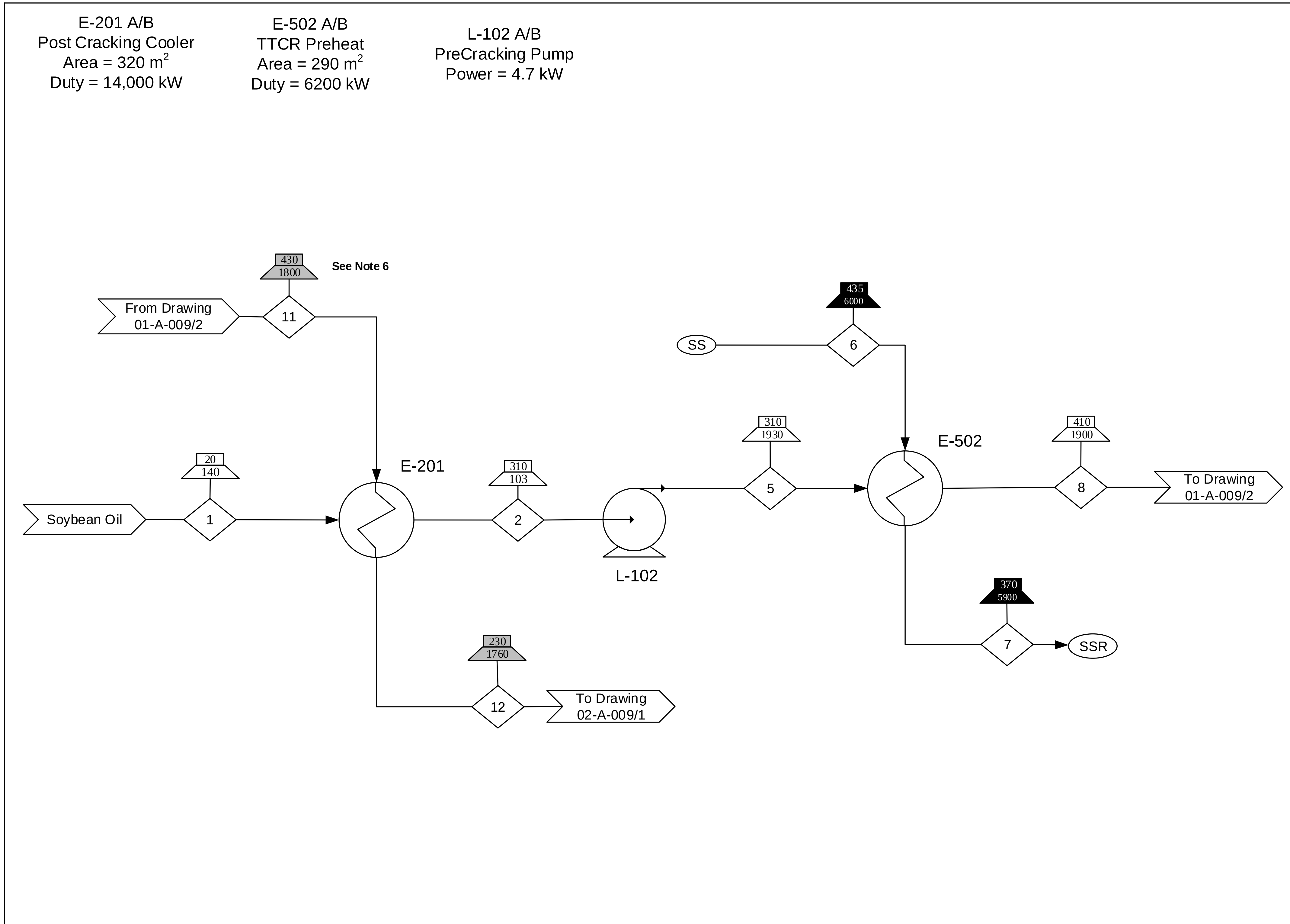
Drawing Type

Block Flow Diagram

Title

Biorefinery Alternative Base Design – Decarboxylation and Trim Purification Sections

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-21-16	00-A-008/4	0



Component/Stream (kg/min)	1	2	5	6	7	8	11	12
Soybean Oil	1000	1000	1000	0	0	1000	0	0
C1-C50	0	0	0	0	0	0	1000	1000
Water	0	0	0	2400	2400	0	0	0
Total	1000	1000	1000	2400	2400	1000	1000	1000

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 11 and 12 is an organic, aqueous, gaseous three phase stream.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°C) Indicator, Liquid/Solid

Pressure (kPa) Indicator, Liquid/Solid

Temperature (°C) Indicator, Gas

Pressure (kPa) Indicator, Gas

Temperature (°C) Indicator, Two Phase

Pressure (kPa) Indicator, Two Phase

SS Superheated Steam

SSR Superheated Steam Recycle

Reference Drawings:

Input/Output Diagram 00-A-007

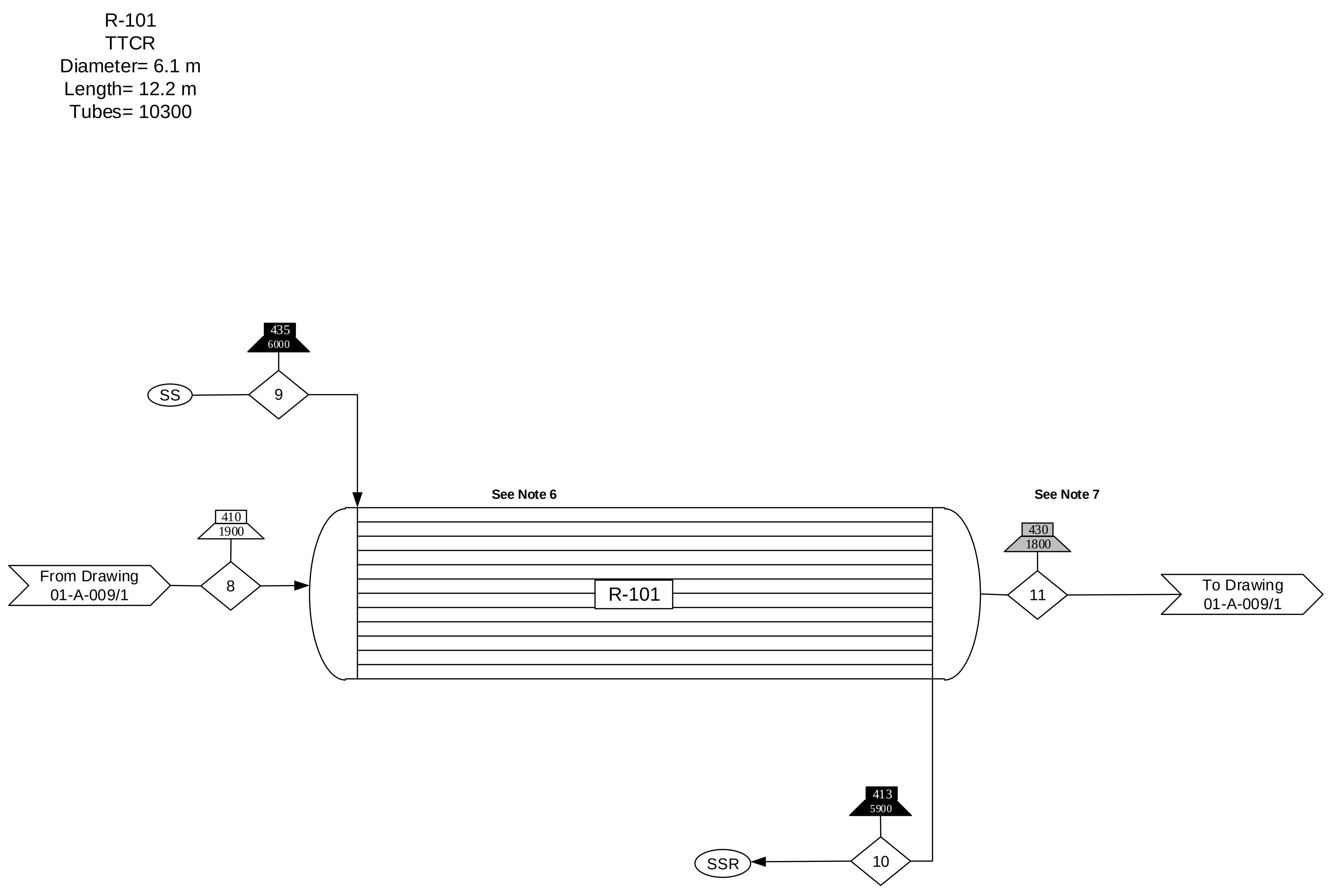
Block Flow Diagrams 00-A-008

Process Flow Diagrams 01-A-009

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design- Thermal Cracking Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-27-16	01-A-009/1	0



Component/Stream (kg/min)	8	9	10	11
Soybean Oil	1000	0	0	0
C1-C50	0	0	0	1000
Water	0	8200	8200	0
Total	1000	8200	8200	1000

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. R-101 has a residence time of 1.17 hr.

7. Stream 11 is composed of a gas phase stream with entrained liquid tars.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase
SS Superheated Steam
SR Superheated Steam Recycle

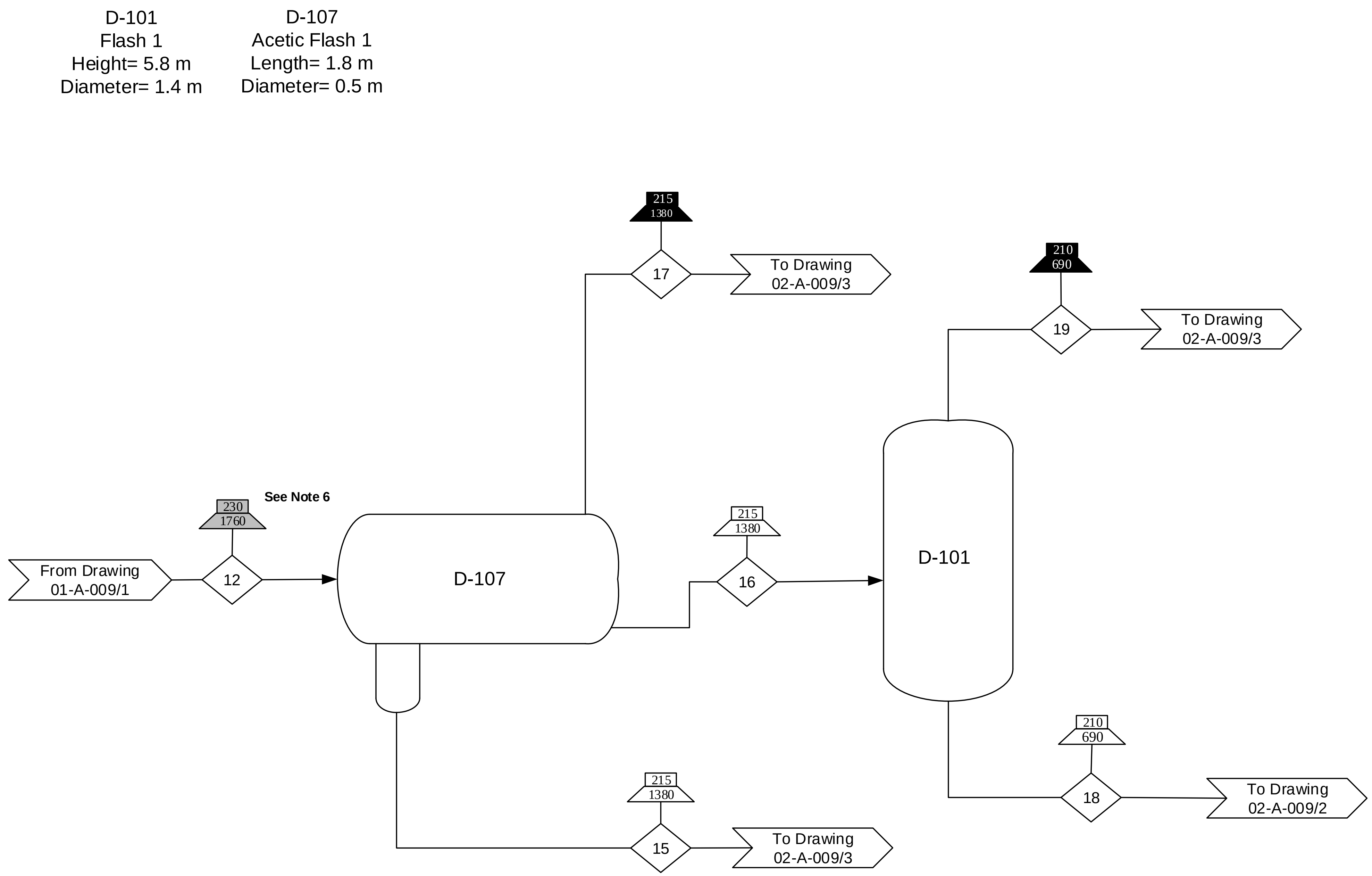
Reference Drawings:

Input/Output Diagram 00-A-007
Block Flow Diagram 00-A-008
Process Flow Diagrams 01-A-009 02-A-009

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design- Thermal Cracking Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-27-16	01-A-009/2	0

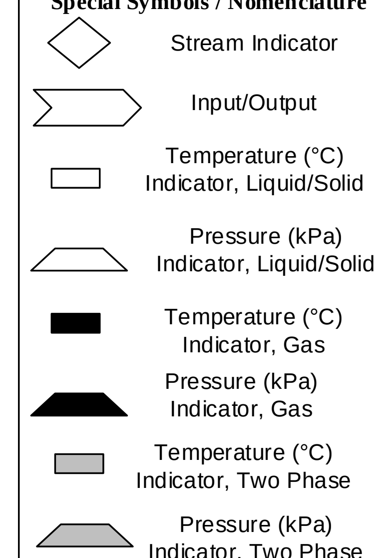


Component/Stream (kg/min)	12	15	16	17	18	19
C1-C50	1000	0	0	0	0	0
C1-C8	0	0	0	210	0	9
C7-C50	0	0	780	0	770	0
Acetic Acid	0	3	0	Trace	0	0
Propionic Acid	0	1	0	0	0	0
Total	1000	4	770	210	770	9

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 12 is composed of an aqueous and organic three phase stream.

Special Symbols / Nomenclature



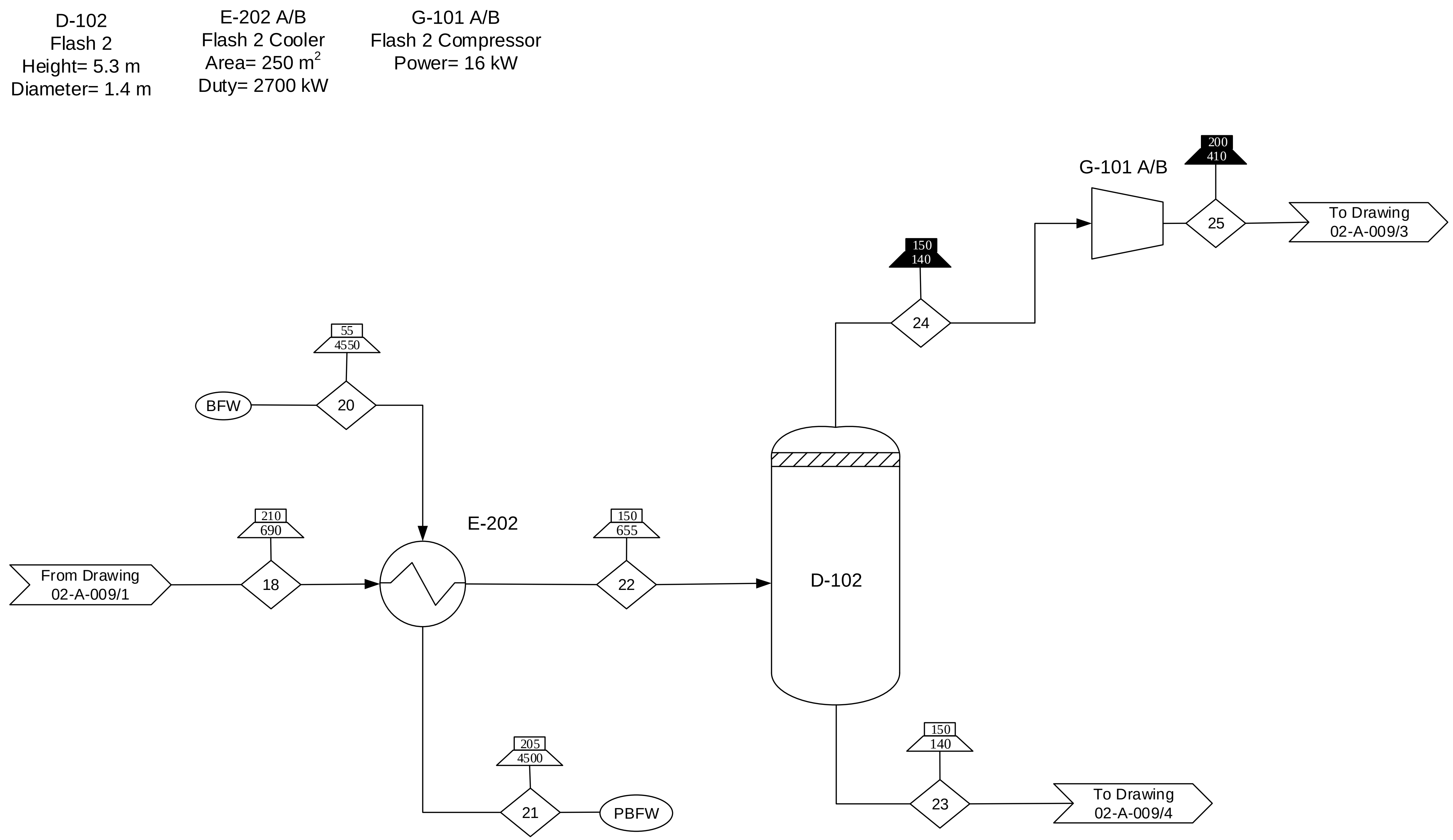
Reference Drawings:

Input/Output Diagrams
00-A-007
Block Flow Diagrams
00-A-008
Process Flow Diagrams
01-A-009
02-A-009

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-28-16	02-A-009/1	0

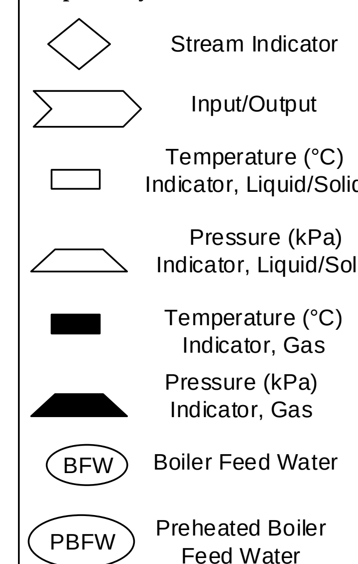


Component/Stream (kg/min)	18	20	21	22	23	24
C1-C8	0	0	0	0	0	9
C7-C50	770	0	0	770	770	0
Water	0	250	250	0	0	0
Total	770	250	250	770	770	9

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



Reference Drawings:

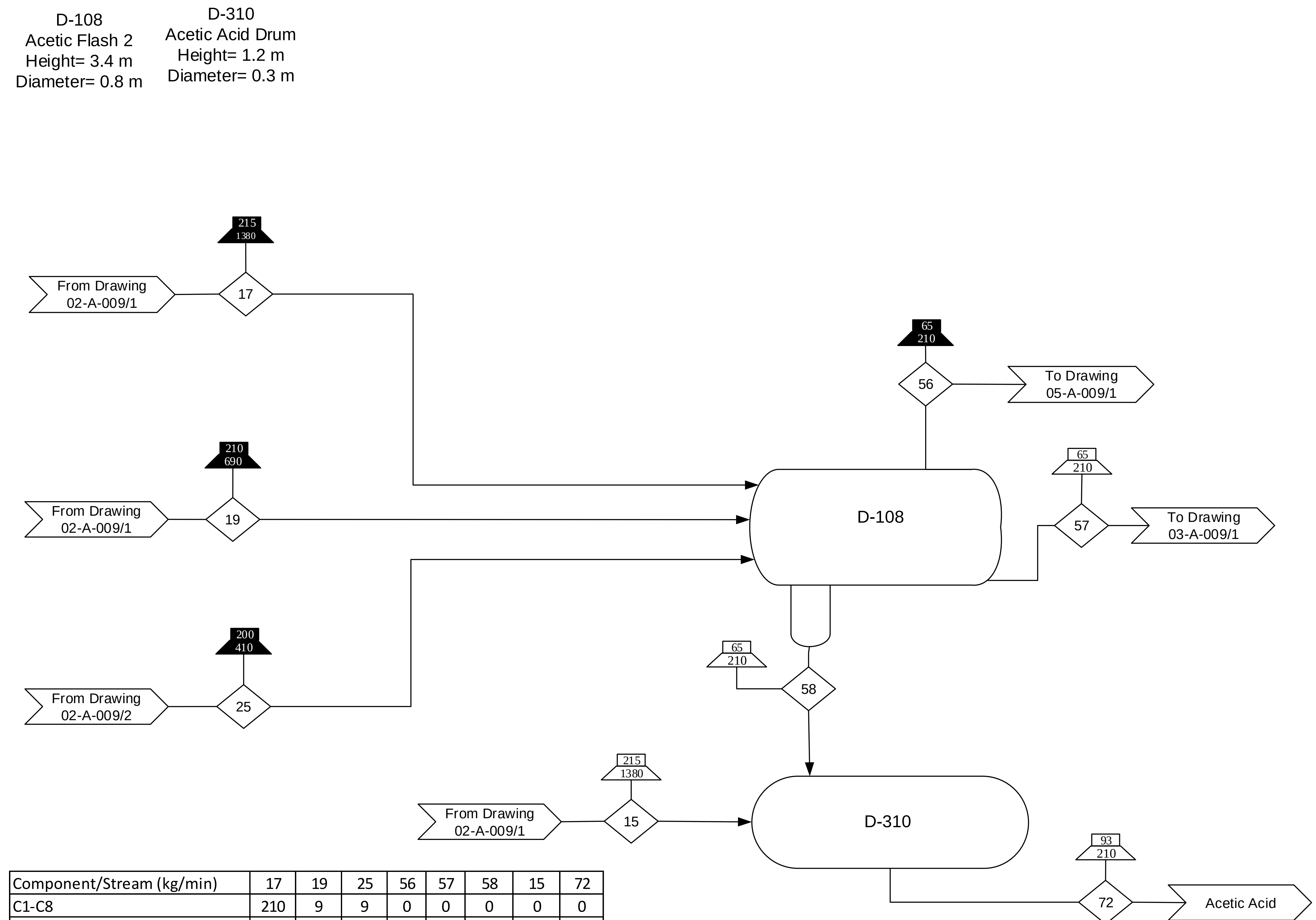
Input/Output Diagrams
00-A-007
Block Flow Diagrams
00-A-008
Process Flow Diagrams
02-A-009

Drawing Type
Process Flow Diagram

Title

Biorefinery Alternative Base Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-28-16	02-A-009/2	0



Component/Stream (kg/min)	17	19	25	56	57	58	15	72
C1-C8	210	9	9	0	0	0	0	0
C1-C6	0	0	0	170	0	0	0	0
C6-C8	0	0	0	0	54	0	0	0
Water	0	0	0	0	0	0	0	0
Acetic Acid	0	Trace	Trace	Trace	0	1	3	4
Propionic Acid	0	Trace	Trace	0	0	Trace	1	1
Total	210	9	9	170	54	1	4	5

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas

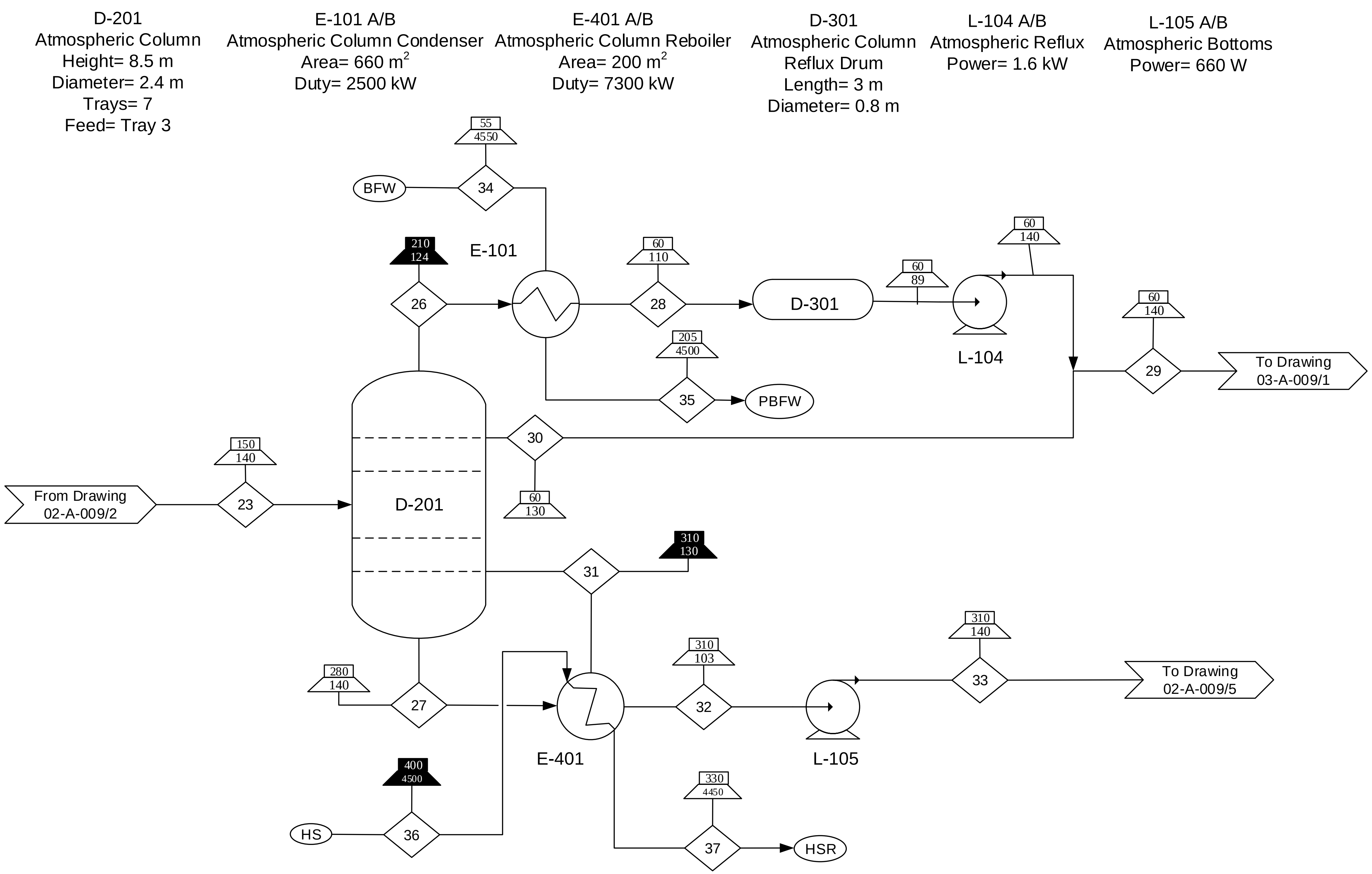
Reference Drawings:

Input/Output Diagram
00-A-007
Block Flow Diagram
00-A-008
Process Flow Diagrams
02-A-009
03-A-009
05-A-009

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-29-16	02-A-009/3	0



Component/Stream (kg/min)	23	26	27	28	29	30	31	32	33	34	35	36	37
C7-C12	0	180	0	180	170	13	0	0	0	0	0	0	0
C7-C50	770	0	1450	0	0	0	860	0	0	0	0	0	0
C13-C50	0	0	0	0	0	0	0	590	590	0	0	0	0
Water	0	0	0	0	0	0	0	0	0	230	230	2500	2500
Total	770	180	1450	180	170	13	860	590	590	230	230	2500	2500

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- HS: High Pressure Steam
- HSR: High Pressure Steam Recycle
- BFW: Boiler Feed Water
- PBFW: Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-007
Block Flow Diagram
00-A-008
Process Flow Diagrams
02-A-009
03-A-009

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-28-16	02-A-009/4	0

D-202
Vacuum Column
Height= 20.4 m
Diameter= 2.9 m
Trays= 20
Feed= Tray 5

E-102 A/B
Vacuum Column Condenser
Area= 120 m^2
Duty= 5600 kW

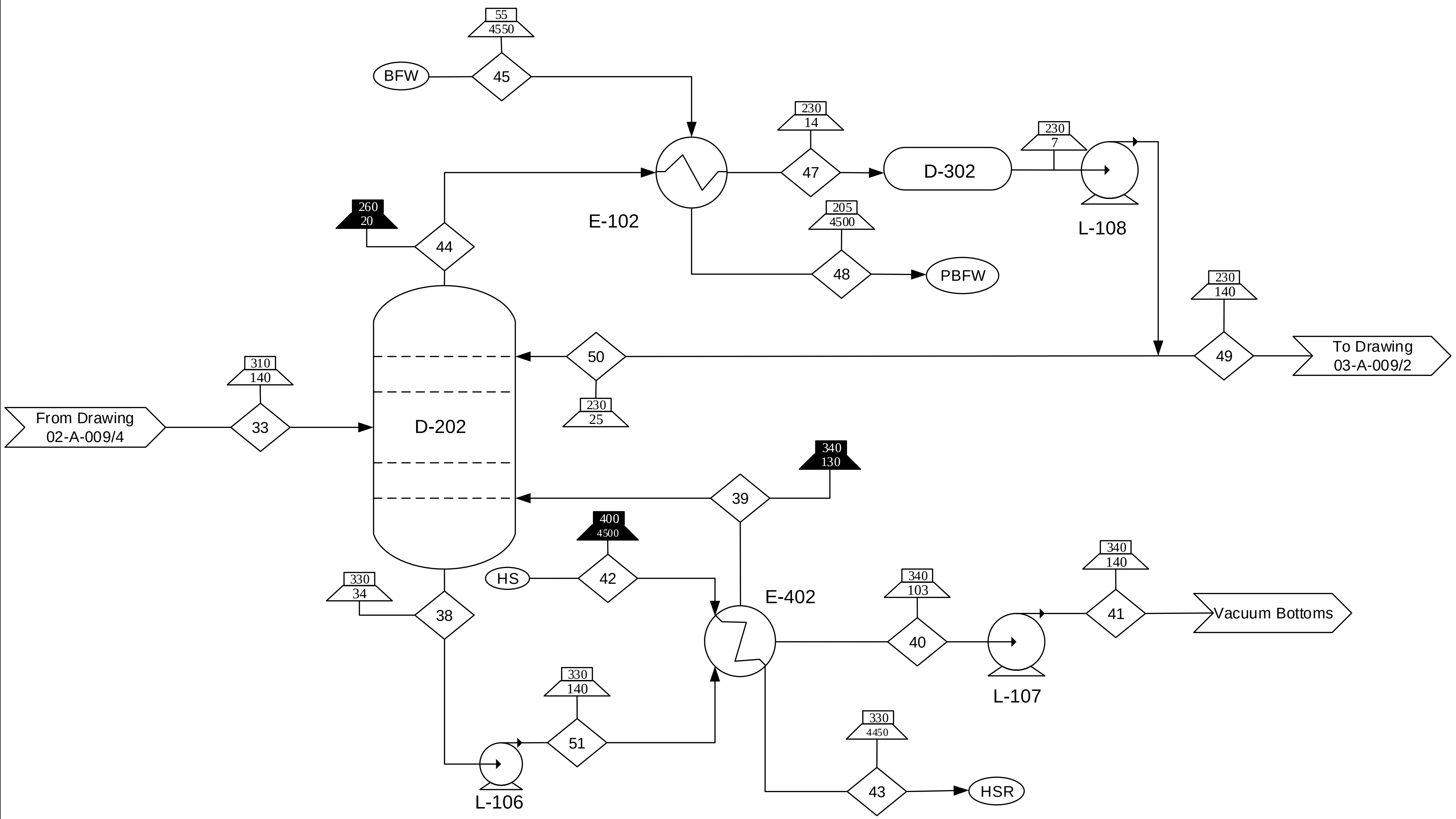
E-402 A/B
Vacuum Column Reboiler
Area= 840 m^2
Duty= 4400 kW

D-302
Vacuum Column
Reflux Drum
Length= 3 m
Diameter= 0.8 m

L-106 A/B
Vacuum Column
Bottoms
Power= 4.3 kW

L-107 A/B
Vacuum Bottoms
Power= 750 W

L-108 A/B
Vacuum Reflux
Power= 4.3 kW



Component/Stream (kg/min)	33	38	39	40	41	42	43	44	45	46	47	48	49	50	51
C12-C50	590	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C12-C30	0	0	0	0	0	0	0	770	0	770	770	0	320	430	0
C30-C50	0	1000	730	1000	280	0	0	0	0	0	0	0	0	0	1000
Water	0	0	0	0	0	1500	1500	0	500	0	0	500	0	0	0
Total	590	1000	730	1000	280	1500	1500	770	500	770	770	500	320	430	1000

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
HS — High Pressure Steam
HSR — High Pressure Steam Recycle
BFW — Boiler Feed Water
PBFW — Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagrams
00-A-007
Block Flow Diagrams
00-A-008
Process Flow Diagrams
02-A-009
03-A-009

Drawing Type
Process Flow Diagram

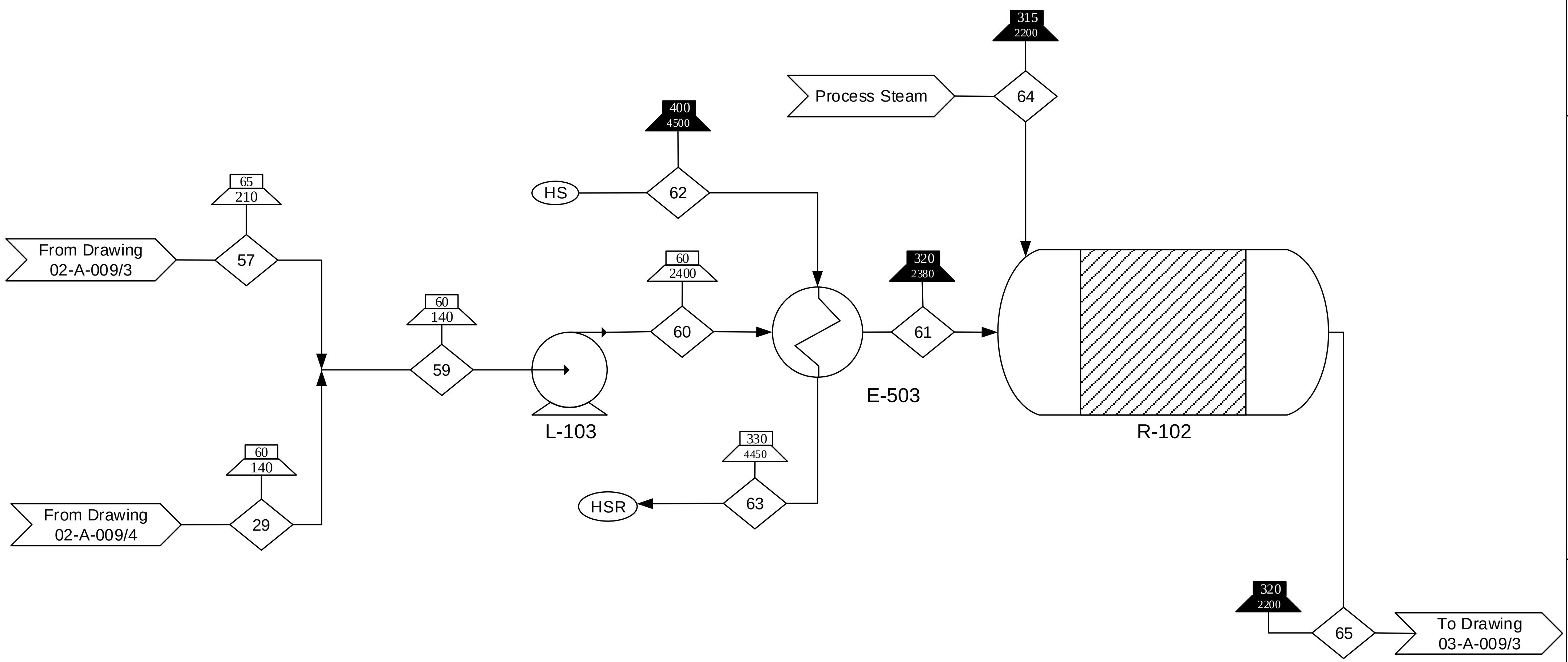
Title
Biorefinery Alternative Base Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-28-16	02-A-009/5	0

R-102 A/B
Naphtha Decarboxylation Reactor
Diameter= 2.7 m
Length= 17 m
Catalyst= 220 m^3

E-503 A/B
Naphtha Decarbox Heater
Area= 43 m^2
Duty= 3800 kW

L-103 A/B
PreNaphtha Decarbox Pump
Power= 17 kW



Component/Stream (kg/min)	29	57	59	60	61	62	63	64	65
C6-C8	0	54	0	0	0	0	0	0	0
C7-C12	170	0	0	0	0	0	0	0	0
C6-C12	0	0	220	220	220	0	0	0	0
C1-C12	0	0	0	0	0	0	0	0	230
Water	0	0	0	0	0	1300	1300	7	0
Total	170	54	220	220	220	1300	1300	7	230

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
HS High Pressure Steam
HSR High Pressure Steam Recycle

Reference Drawings:

Input/Output Diagram
00-A-007
Block Flow Diagram
00-A-008
Process Flow Diagrams
02-A-009
03-A-009

Drawing Type
Process Flow Diagram

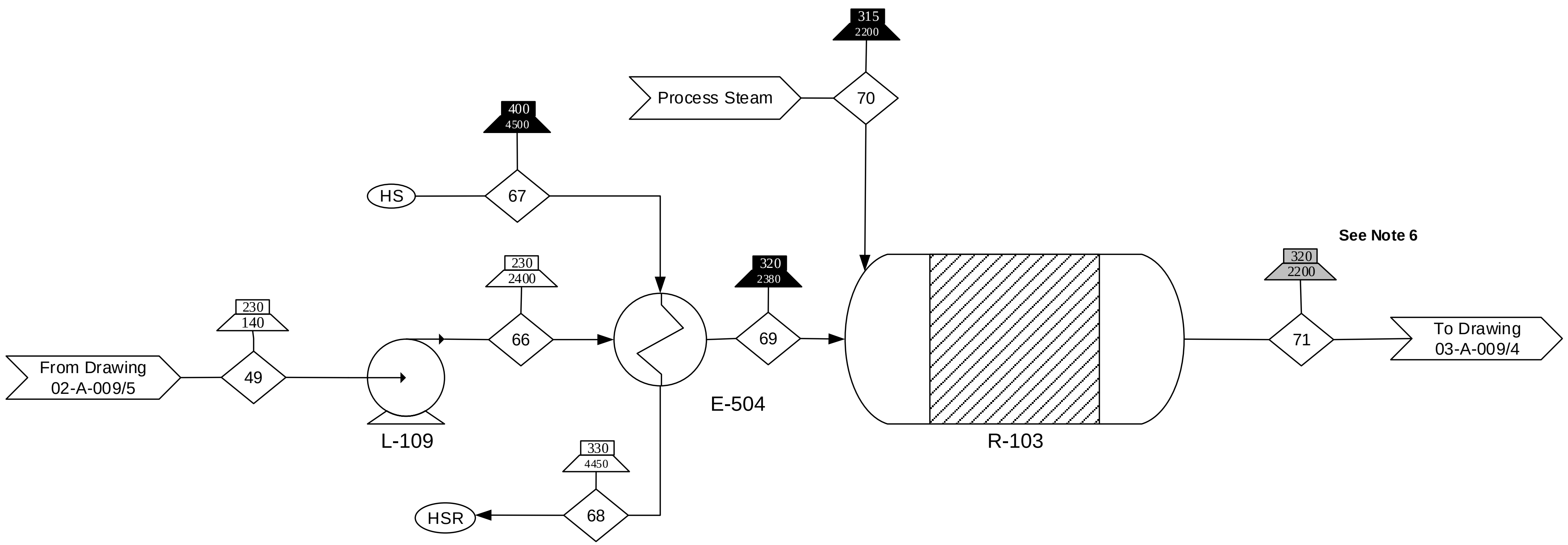
Title
Biorefinery Alternative Base Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-29-16	03-A-009/1	0

R-103 A/B
Diesel Decarboxylation Reactor
Diameter= 3.4 m
Length= 19 m
Catalyst= 310 m^3

E-504 A/B
Diesel Decarbox Heater
Area= 40 m^2
Duty= 1800 kW

L-109 A/B
Pre Diesel Decarbox Pump
Power= 29 kW



Component/Stream (kg/min)	49	66	67	68	69	70	71
C12-C30	320	320	0	0	320	0	0
C1-C30	0	0	0	0	0	0	330
Water	0	0	640	640	0	10	0
Total	320	320	640	640	320	10	330

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 71 is composed of a liquid gas two phase stream.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- Temperature (°C) Indicator, Two Phase
- Pressure (kPa) Indicator, Two Phase
- HS High Pressure Steam
- HSR High Pressure Steam Recycle

Reference Drawings:

Input/Output Diagram
00-A-007
Block Flow Diagram
00-A-008
Process Flow Diagrams
02-A-009
03-A-009

Drawing Type
Process Flow Diagram

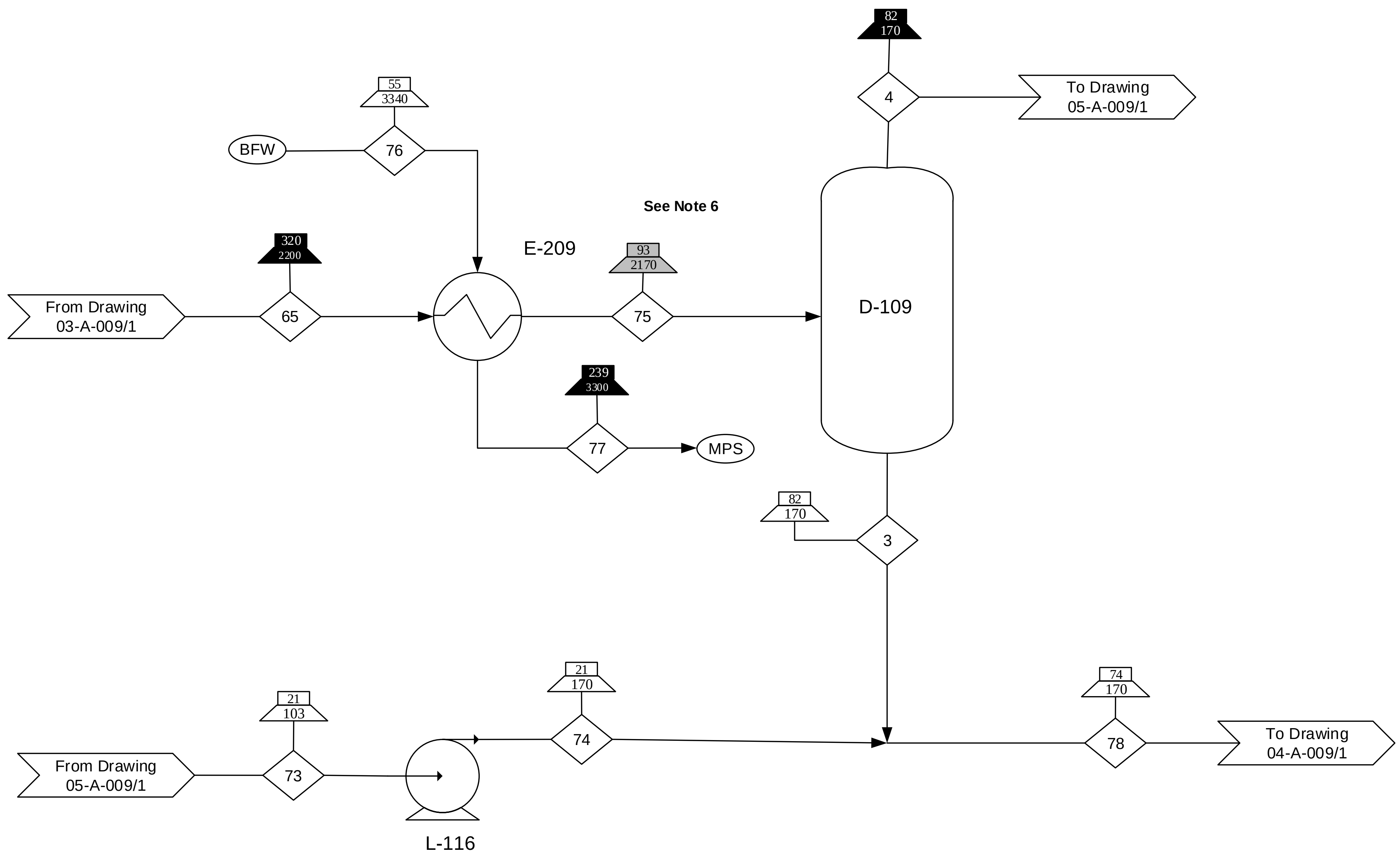
Title
Biorefinery Alternative Base Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-29-16	03-A-009/2	0

D-109
Flash 7
Height= 2.7 m
Diameter= 0.8 m

E-209 A/B
Post Naphtha Decarbox Cooler
Area = 74 m^2
Duty = 3500 kW

L-116 A/B
Flash 5 Pump
Power = 52 W



Component/Stream (kg/min)	65	73	74	75	76	77	3	4	78
C1-C12	230	0	0	230	0	0	0	0	210
C6-C9	0	23	23	0	0	0	0	0	0
C1-C4	0	0	0	0	0	0	0	45	0
C4-C12	0	0	0	0	0	0	190	0	0
Water	0	0	0	0	90	90	0	0	0
Total	230	23	23	230	90	90	190	45	210

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 75 is composed of a liquid and gas two phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
MPS Medium Pressure Steam
BFW Boiler Feed Water

Reference Drawings:

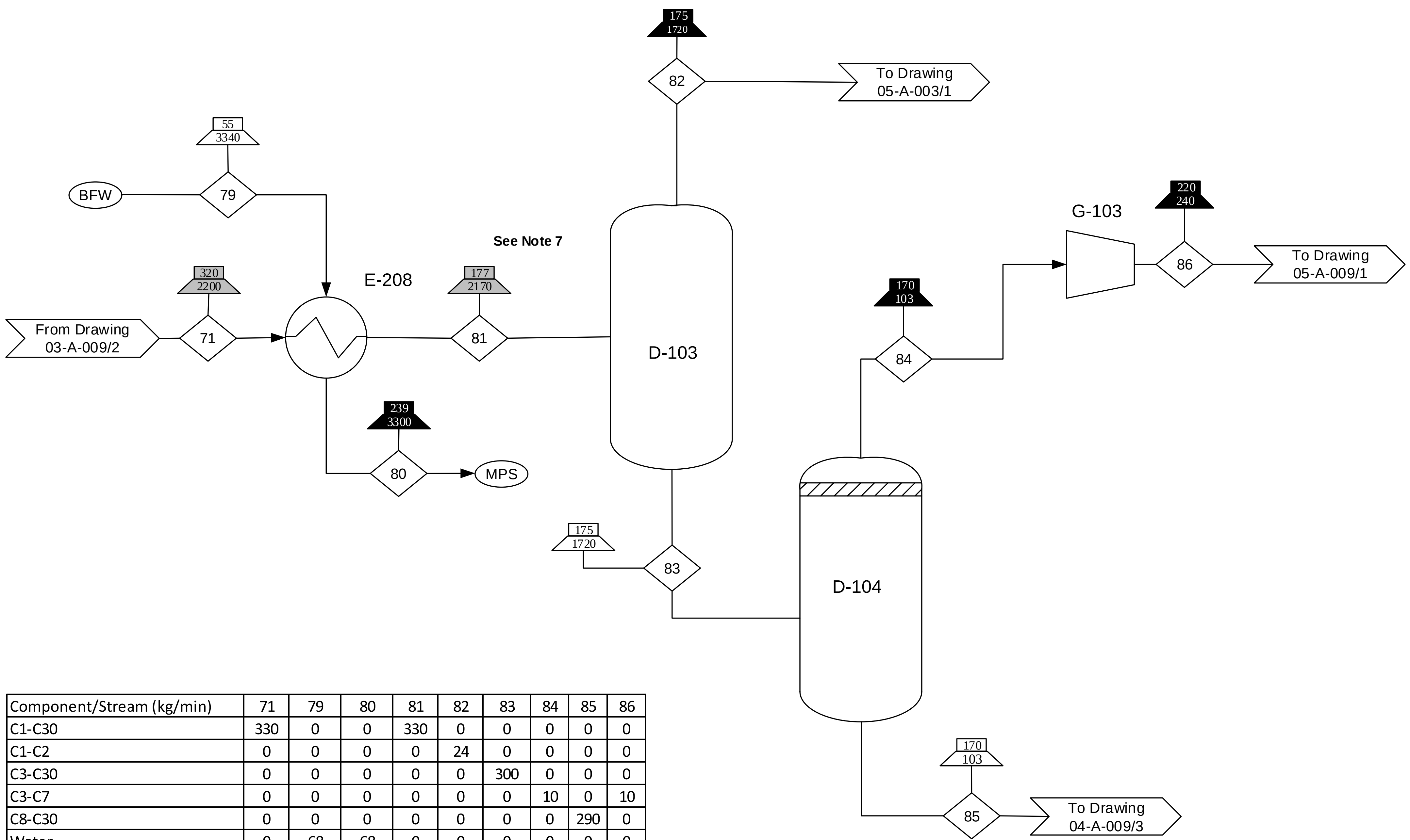
Input/Output Diagram
00-A007
Block Flow Diagram
00-A-008
Process Flow Diagrams
03-A-009
04-A-009
05-A-009

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-29-16	03-A-009/3	0

D-103	D-104	E-208 A/B	G-103 A/B
Flash 3	Flash 4	Post Diesel Decarbox Cooler	Flash 5 Compressor
Height= 4.9 m	Height= 4.7 m	Area= 33 m^2	Power= 15 kW
Diameter= 1.2 m	Diameter= 1.2 m	Duty= 2900 kW	



Component/Stream (kg/min)	71	79	80	81	82	83	84	85	86
C1-C30	330	0	0	330	0	0	0	0	0
C1-C2	0	0	0	0	24	0	0	0	0
C3-C30	0	0	0	0	0	300	0	0	0
C3-C7	0	0	0	0	0	0	10	0	10
C8-C30	0	0	0	0	0	0	0	290	0
Water	0	68	68	0	0	0	0	0	0
Total	330	68	68	330	24	300	10	290	10

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
7. Streams 71 and 81 are composed of a liquid and gas two phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase
MPS Medium Pressure Steam
BFW Boiler Feed Water

Reference Drawings:
Process Flow Diagrams
03-A-009
04-A-009
05-A-009

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-29-16	03-A-009/4	0

D-203
Hexane Splitter
Height= 11.9 m
Diameter= 1.5 m
Trays= 12
Feed= Tray 4

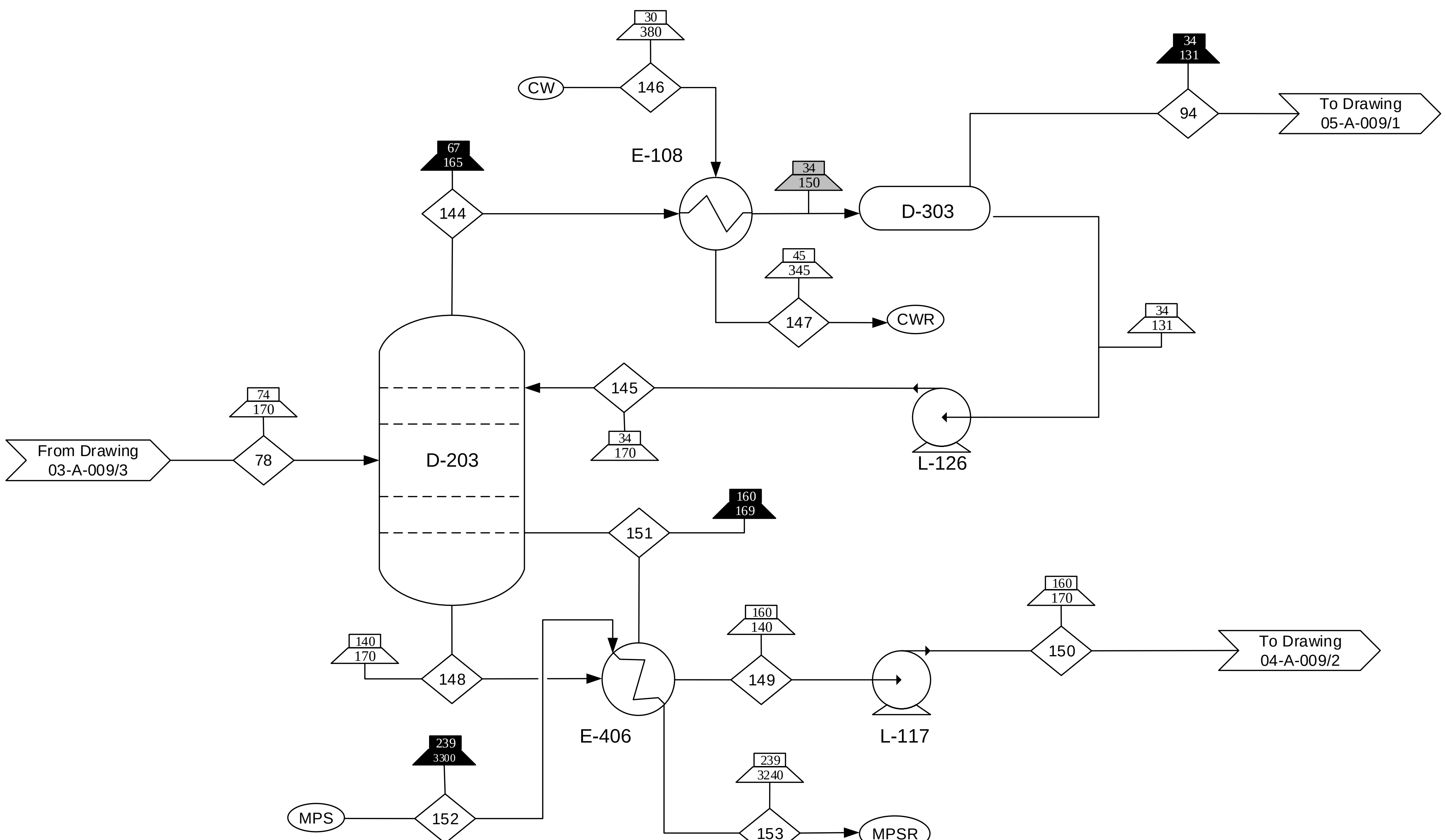
E-108 A/B
Hexane Splitter Condenser
Area= 280 m^2
Duty= 1400 kW

E-406 A/B
Hexane Splitter Reboiler
Area= 64 m^2
Duty= 2300 kW

D-303
Hexane Splitter
Reflux Drum
Length= 3.7 m
Diameter= 0.9 m

L-117 A/B
Hexane Splitter Bottoms
Power= 2.2 kW

L-126 A/B
Hexane Splitter Reflux
Power= 750 W



Notes
1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature
- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- Temperature (°C) Indicator, Two Phase
- Pressure (kPa) Indicator, Two Phase
- MPS Medium Pressure Steam
- MPSR Medium Pressure Steam Recycle
- CW Cooling Water
- CWR Cooling Water Recycle

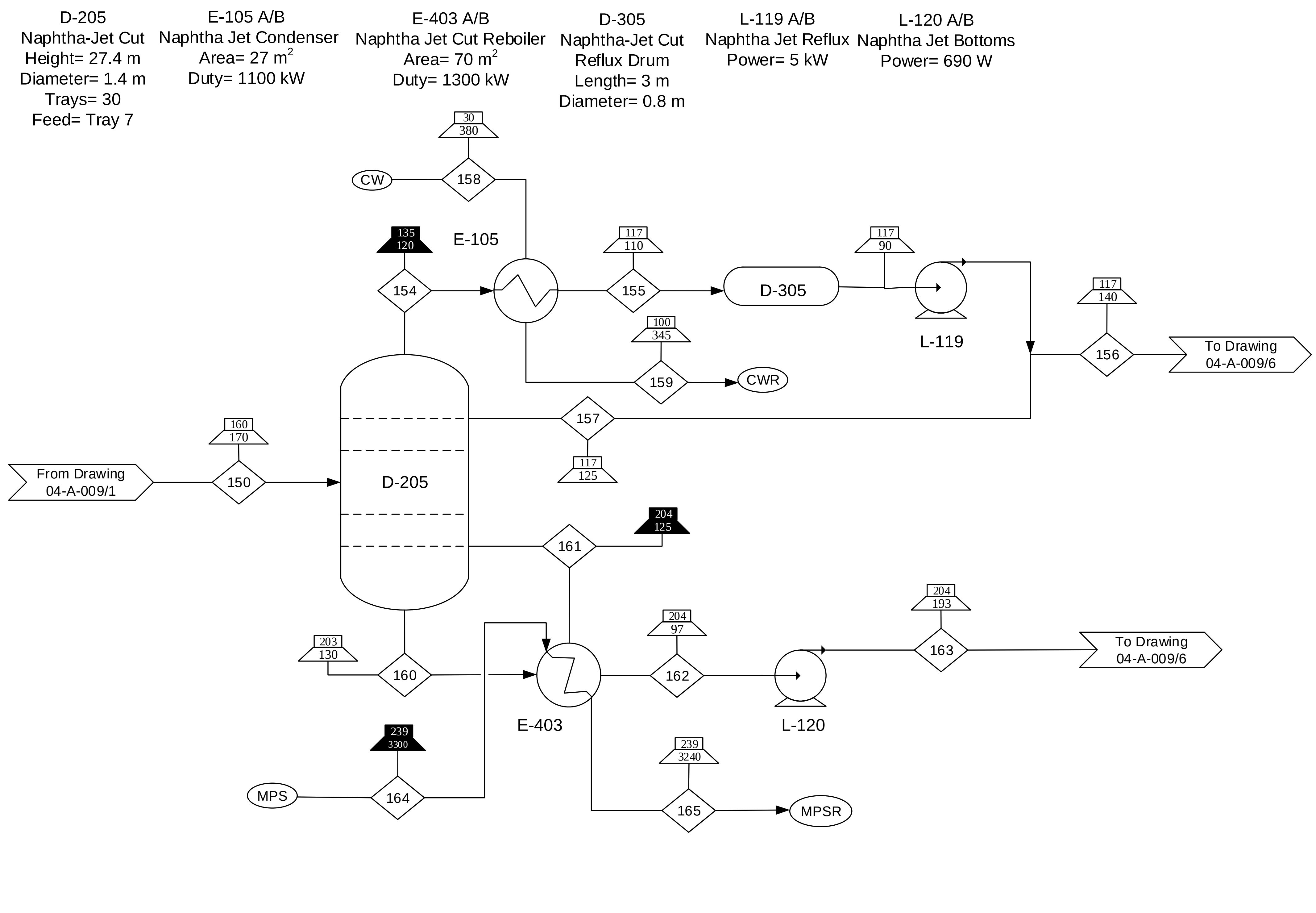
Component/Stream (kg/min)	78	94	144	145	146	147	148	149	150	151	152	153
C1-C12	210	0	0	0	0	0	0	0	0	0	0	0
C1-C6	0	14	170	110	0	0	0	0	0	0	0	0
C7-C12	0	0	0	0	0	0	500	190	190	310	0	0
Water	0	0	0	0	1400	1400	0	0	0	0	77	77
Total	210	14	170	110	1400	1400	500	190	190	310	77	77

Reference Drawings:
Input/Output Diagram
00-A-007
Block Flow Diagram
00-A-008
Process Flow Diagrams
03-A-009
04-A-009
05-A-009

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-3-17	04-A-009/1	0



Component/Stream (kg/min)	150	154	155	156	157	158	159	160	161	162	163	164	165
C7-C12	190	0	0	0	0	0	0	0	0	0	0	0	0
C7-C9	0	150	68	68	82	0	0	0	0	0	0	0	0
C9-C12	0	0	0	0	0	0	0	330	200	120	120	0	0
Water	0	0	0	0	0	1000	1000	0	0	0	0	45	45
Total	190	150	68	68	82	1000	1000	330	200	120	120	45	45

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- MPS — Medium Pressure Steam
- MPSR — Medium Pressure Steam Recycle
- CW — Cooling Water
- CWR — Cooling Water Recycle

Reference Drawings:

Input/Output Diagram
00-A-007
Block Flow Diagram
00-A-008
Process Flow Diagrams
04-A-009

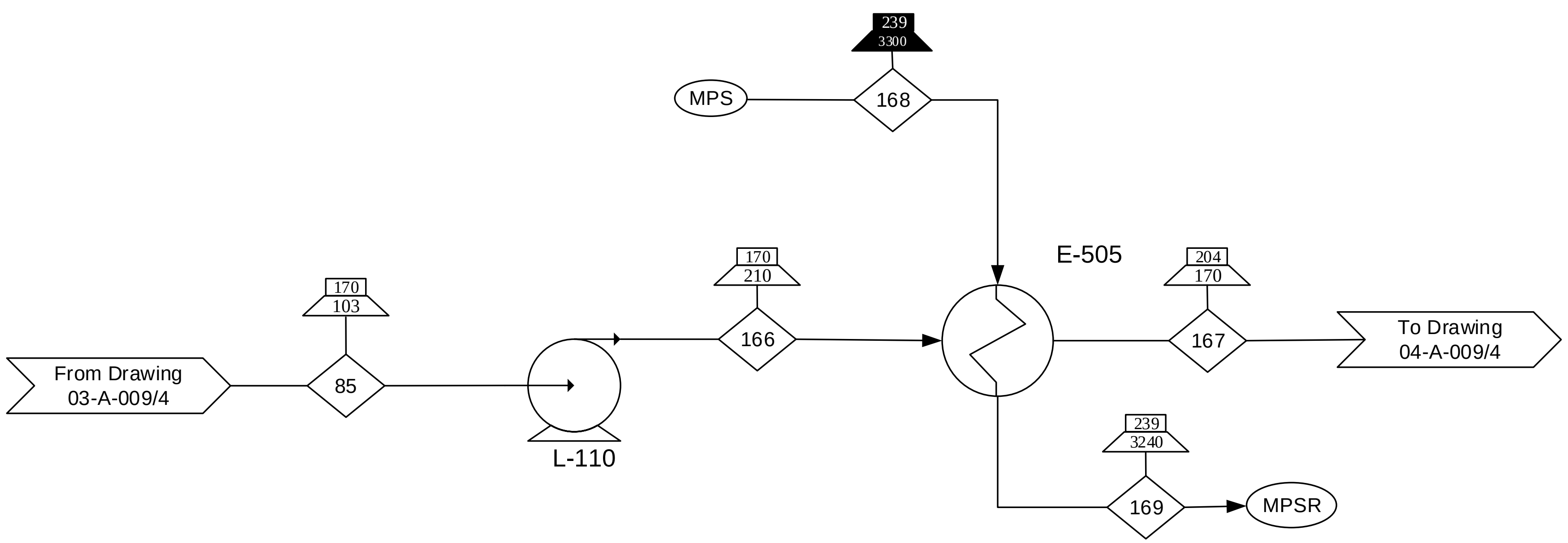
Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-3-17	04-A-009/2	0

E-505 A/B
Pre Jet Diesel Cut Heat
Area = 22 m^2
Duty = 530 kW

L-110 A/B
Pre Jet Diesel Cut Heat Pump
Power = 1.8 kW



Component/Stream (kg/min)	85	166	167	168	169
C8-C30	290	290	290	0	0
Water	0	0	0	18	18
Total	290	290	290	18	18

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
MPS — Medium Pressure Steam
MPSR — Medium Pressure Steam Recycle

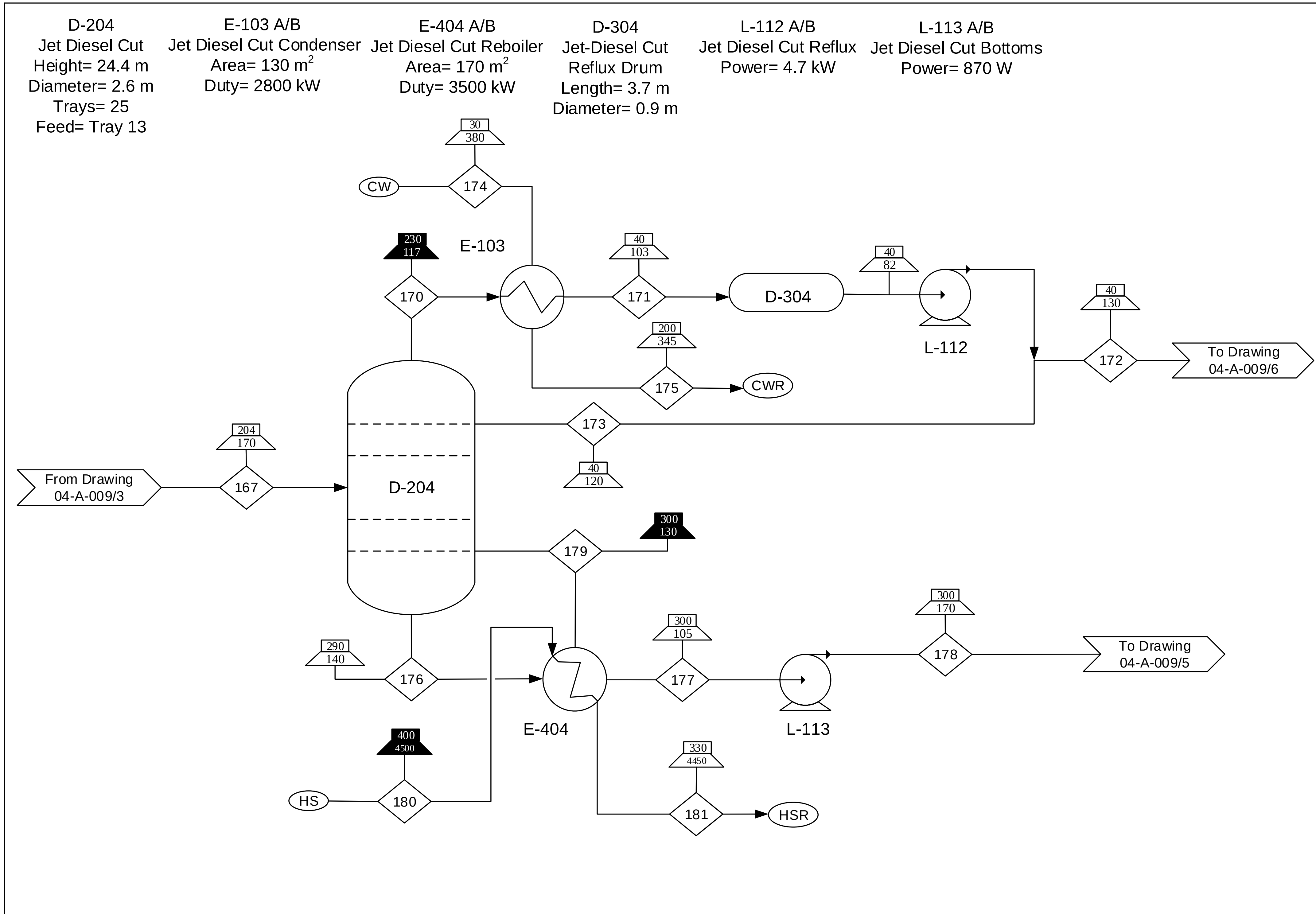
Reference Drawings:

Input/Output Diagram
00-A-007
Block Flow Diagram
00-A-008
Process Flow Diagrams
03-A-009
04-A-009

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-3-17	04-A-009/3	0



Component/Stream (kg/min)	167	170	171	172	173	174	175	176	177	178	179	180	181
C8-C30	290	0	0	0	0	0	0	0	0	0	0	0	0
C8-C15	0	190	190	73	110	0	0	0	0	0	0	0	0
C16-C30	0	0	0	0	0	0	0	860	220	220	640	0	0
Water	0	0	0	0	0	2700	2700	0	0	0	0	1200	1200
Total	290	190	190	73	110	2700	2700	860	220	220	640	1200	1200

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- HS High Pressure Steam
- HSR High Pressure Steam Recycle
- CW Cooling Water
- CWR Cooling Water Recycle

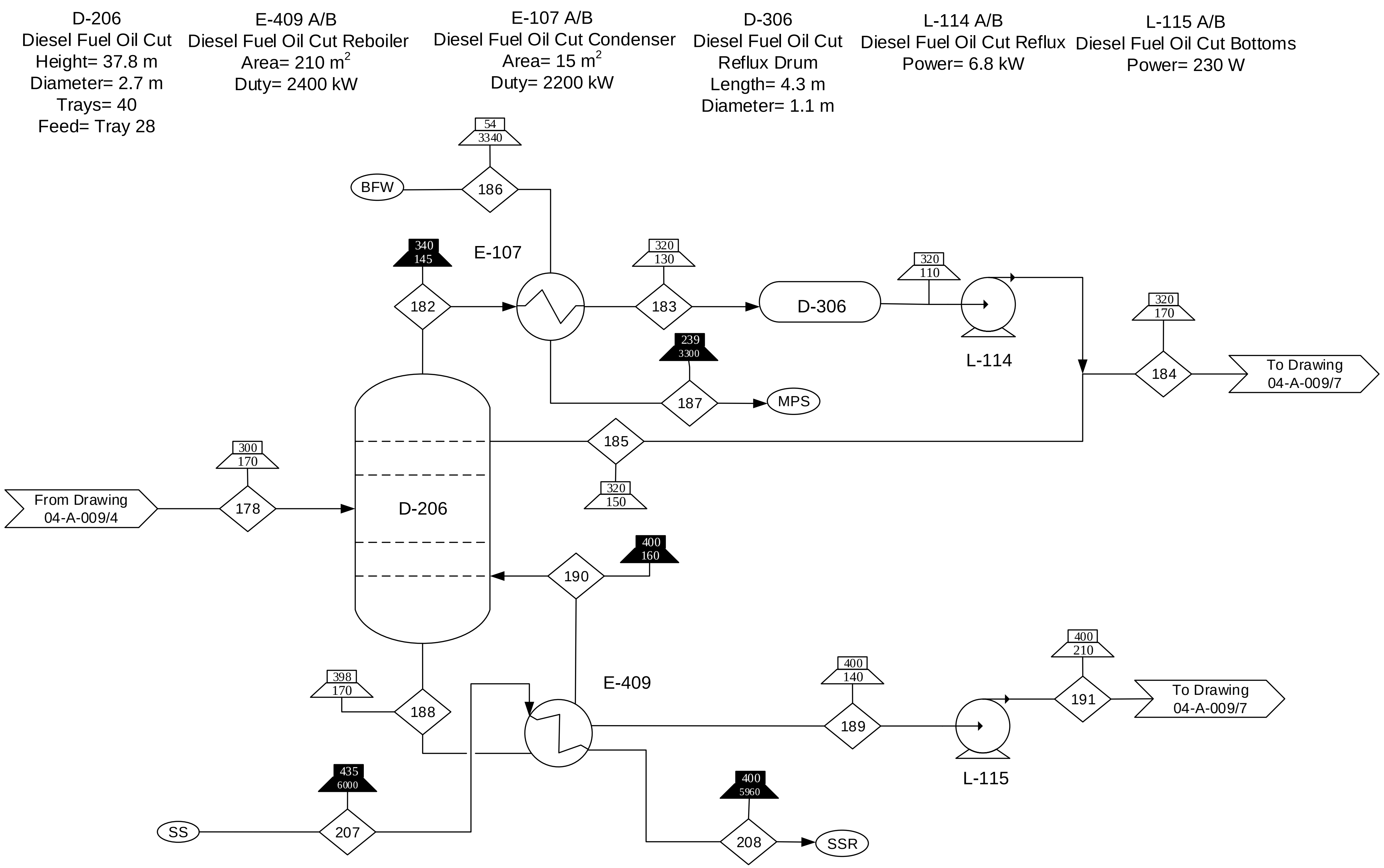
Reference Drawings:

Input/Output Diagram 00-A-007
Block Flow Diagram 00-A-008
Process Flow Diagrams 04-A-009

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-3-17	04-A-009/4	0



Component/Stream (kg/min)	178	182	183	184	185	186	187	188	189	190	191	207	208
C16-C30	220	0	0	0	0	0	0	0	0	0	0	0	0
C16-C21	0	380	380	210	160	0	0	0	0	0	0	0	0
C22-C30	0	0	0	0	0	0	0	340	5	640	5	0	0
Water	0	0	0	0	0	54	54	0	0	0	0	3000	3000
Total	220	380	380	210	160	54	54	340	5	640	5	3000	3000

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- MPS: Medium Pressure Steam
- BFW: Boiler Feed Water
- SS: Superheated Steam
- SSR: Superheated Steam Recycle

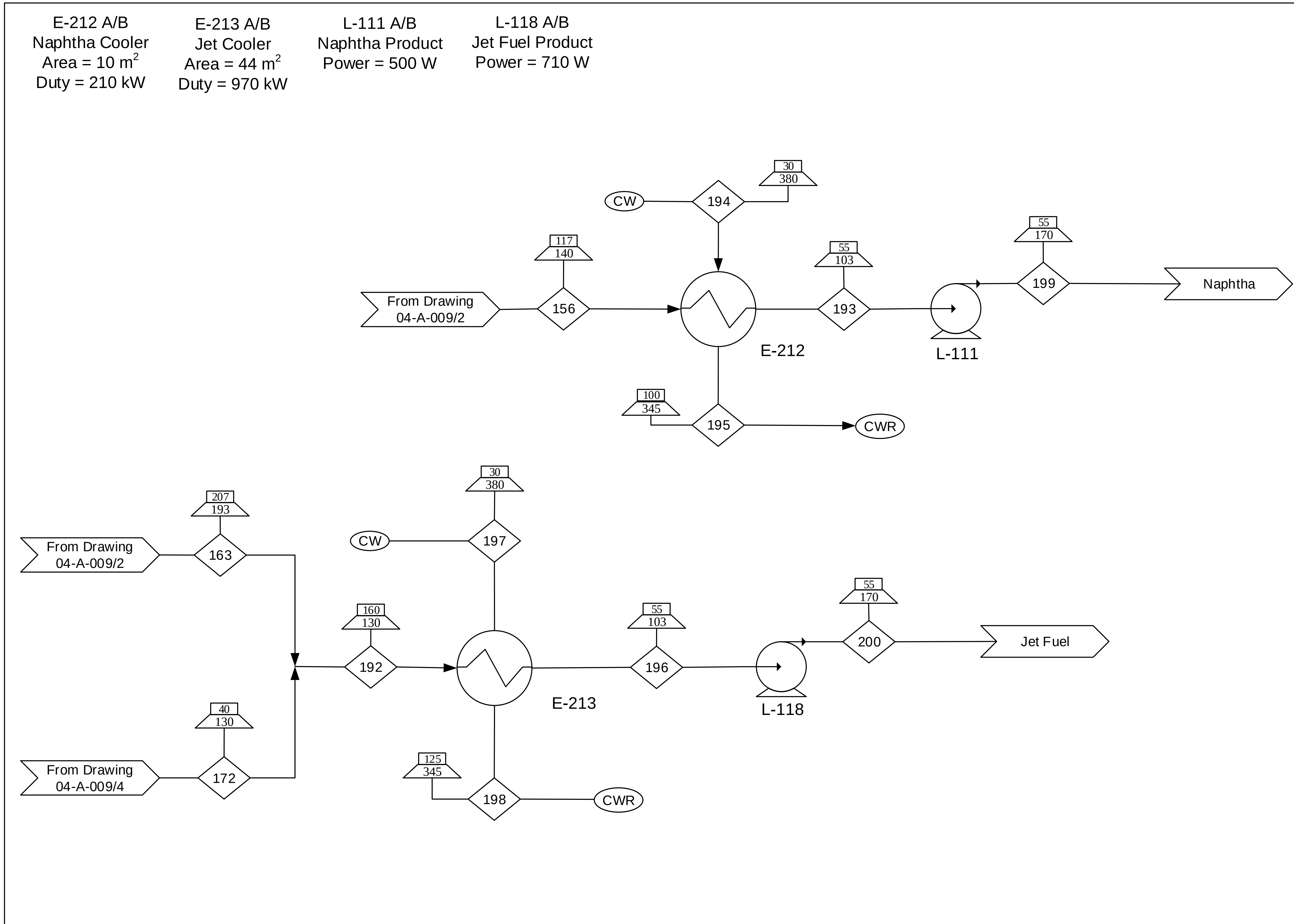
Reference Drawings:

Input/Output Diagram
00-A-007
Block Flow Diagram
00-A-008
Process Flow Diagrams
04-A-009

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-3-17	04-A-009/5	0



Component/Stream (kg/min)	156	163	172	192	193	194	195	196	197	198	199	200
Naphtha Product	68	0	0	0	68	0	0	0	0	0	68	0
Jet Fuel Product	0	120	73	200	0	0	0	200	0	0	0	200
Water	0	0	0	0	0	200	200	0	950	950	0	0
Total	68	120	73	200	68	200	200	200	950	950	68	200

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°C) Indicator, Liquid/Solid
- Pressure (kPa) Indicator, Liquid/Solid
- Temperature (°C) Indicator, Gas
- Pressure (kPa) Indicator, Gas
- CW — Cooling Water
- CWR — Cooling Water Recycle

Reference Drawings:

Input/Output Diagram 00-A-007
Block Flow Diagram 00-A-008
Process Flow Diagrams 04-A-009

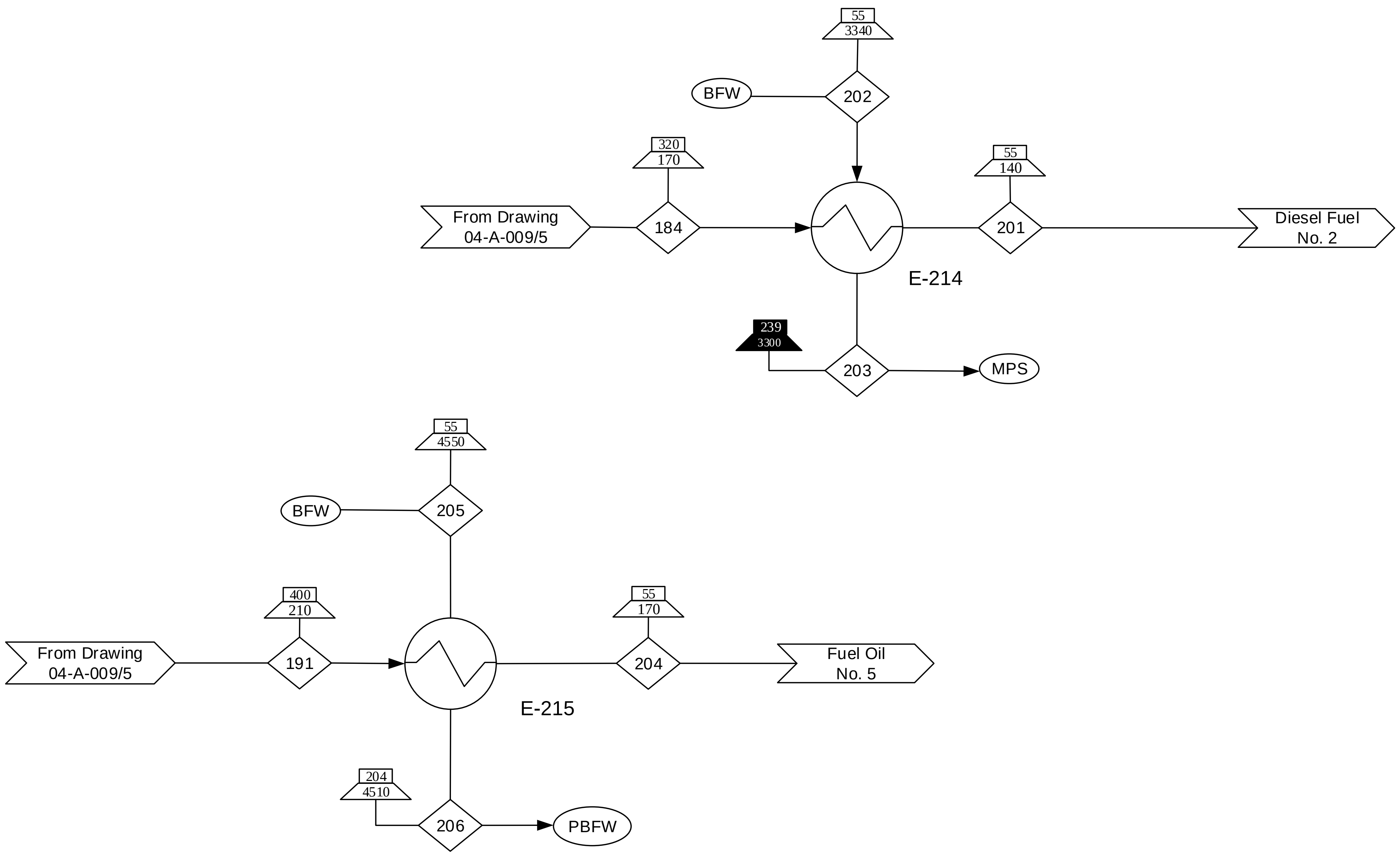
Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-4-17	04-A-009/6	0

E-214 A/B
Diesel Cooler
Area = 130 m^2
Duty = 3200 kW

E-215 A/B
Fuel Oil Cooler
Area = 2 m^2
Duty = 82 kW



Component/Stream (kg/min)	184	191	201	202	203	204	205	206
Diesel Fuel No. 2 Product	210	0	210	0	0	0	0	0
Fuel Oil No. 5 Product	0	5	0	0	0	5	0	0
Water	0	0	0	77	77	0	23	23
Total	210	5	210	77	77	5	23	23

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
MPS Medium Pressure Steam
BFW Boiler Feed Water
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

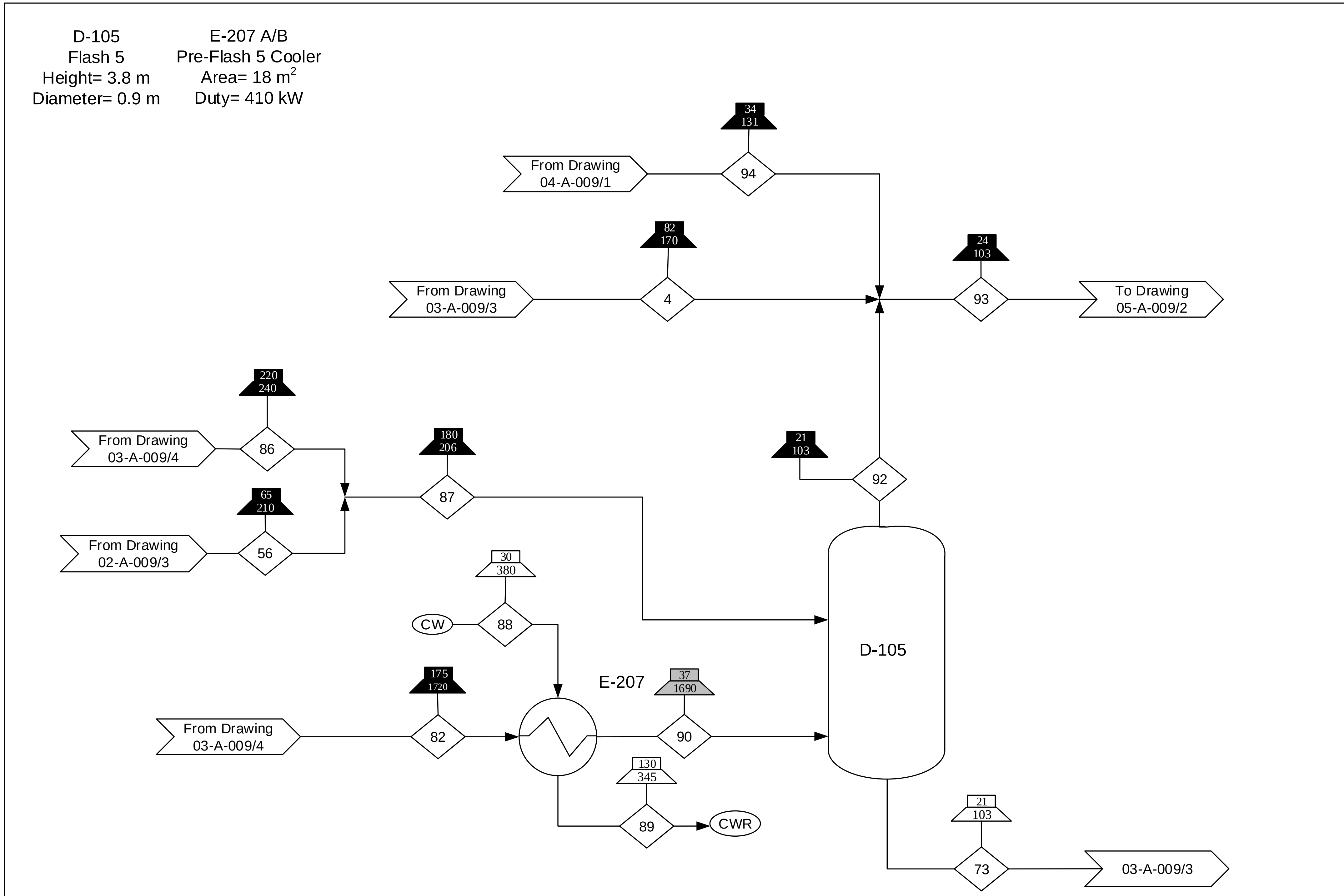
Reference Drawings:

Input/Output Diagram
00-A-007
Block Flow Diagram
00-A-008
Process Flow Diagrams
04-A-009

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-4-17	04-A-009/7	0



Component/Stream (kg/min)	4	56	73	82	86	87	88	89	90	92	93	94
C1-C2	0	0	0	24	0	0	0	0	24	0	0	0
C3-C7	0	0	0	0	10	0	0	0	0	0	0	0
C1-C7	0	0	0	0	0	0	0	0	0	0	0	0
C1-C6	45	170	0	0	0	180	0	0	0	190	240	14
C6-C7	0	0	23	0	0	0	0	0	0	0	0	0
Water	0	0	0	0	0	0	390	390	0	0	0	0
Total	45	170	23	24	10	180	390	390	24	190	240	14

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase
CW Cooling Water
CWR Cooling Water Recycle

Reference Drawings:

Input/Output Diagram
00-A-007
Block Flow Diagram
00-A-008
Process Flow Diagrams
02-A-009
03-A-009
04-A-009
05-A-009

Drawing Type
Process Flow Diagram

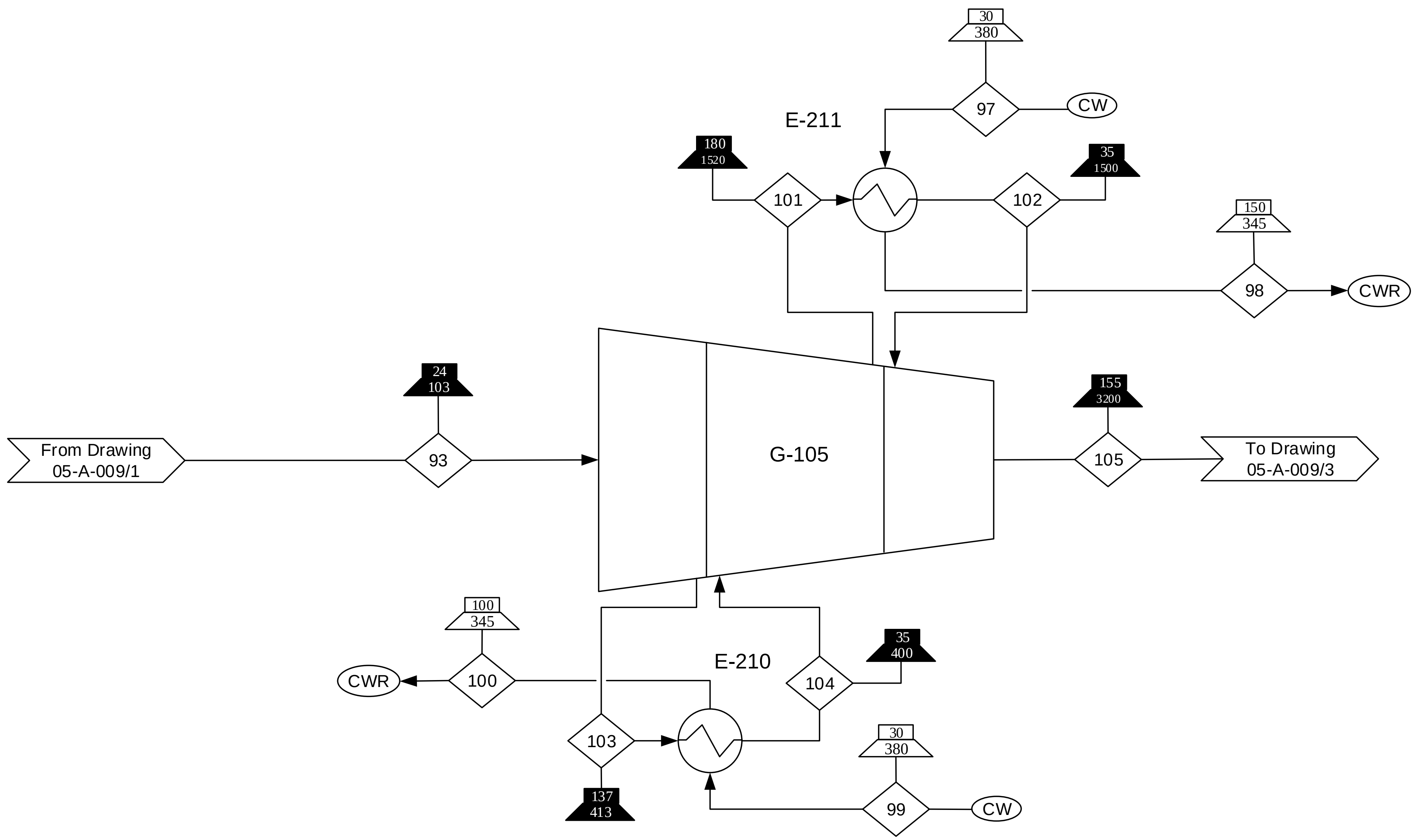
Title
Biorefinery Alternative Base Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-29-16	05-A-009/1	0

G-105
Light End Compressor
3 Stages
Stage 1 Power = 800 kW
Stage 2 Power = 800 kW
Stage 3 Power = 800 kW

E-210 A/B
Interstage Cooler 1
Area= 30 m^2
Duty= 670 kW

E-211 A/B
Interstage Cooler 2
Area= 18 m^2
Duty= 820 kW



Component/Stream (kg/min)	93	97	98	99	100	101	102	103	104	105
C1-C6	240	0	0	0	0	240	240	240	240	240
Water	0	770	770	640	640	0	0	0	0	0
Total	240	770	770	640	640	240	240	240	240	240

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
CW Cooling Water
CWR Cooling Water Recycle

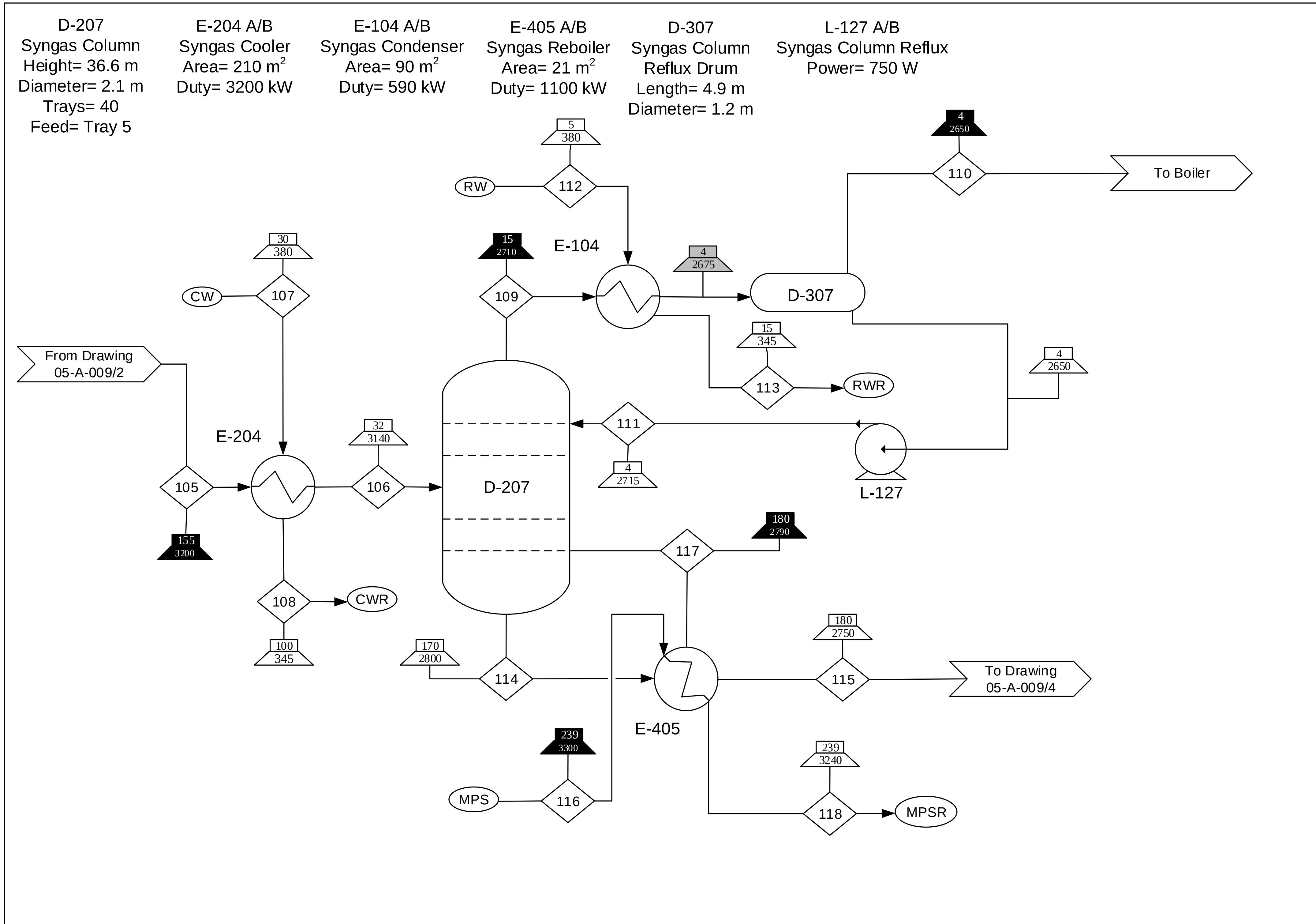
Reference Drawings:

Input/Output Diagram
00-A-007
Block Flow Diagram
00-A-008
Process Flow Diagrams
04-A-009
05-A-009

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-2-17	05-A-009/2	0



Component/Stream (kg/min)	105	106	107	108	109	110	111	112	113	114	115	116	117	118
C1-C6	240	240	0	0	0	0	0	0	0	0	0	0	0	0
C1-C3	0	0	0	0	240	160	77	0	0	0	0	0	0	0
C4-C6	0	0	0	0	0	0	0	0	0	350	86	0	270	0
Water	0	0	3000	3000	0	0	0	540	540	0	0	39	0	39
Total	240	240	3000	3000	240	160	77	540	540	350	86	39	270	39

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
Temperature (°C) Indicator, Two Phase
Pressure (kPa) Indicator, Two Phase
MPS Medium Pressure Steam
MPSR Medium Pressure Steam Recycle
RW Refrigerated Water
RWR Refrigerated Water Recycle

Reference Drawings:

Input/Output Diagram 00-A-007
Block Flow Diagram 00-A-008
Process Flow Diagrams 05-A-009

Drawing Type
Process Flow Diagram
Title
Biorefinery Alternative Base Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-2-17	05-A-009/3	0

D-210
Debutanizer Column
Height= 14 m
Diameter= 3.5 m
Trays= 12
Feed= Tray 8

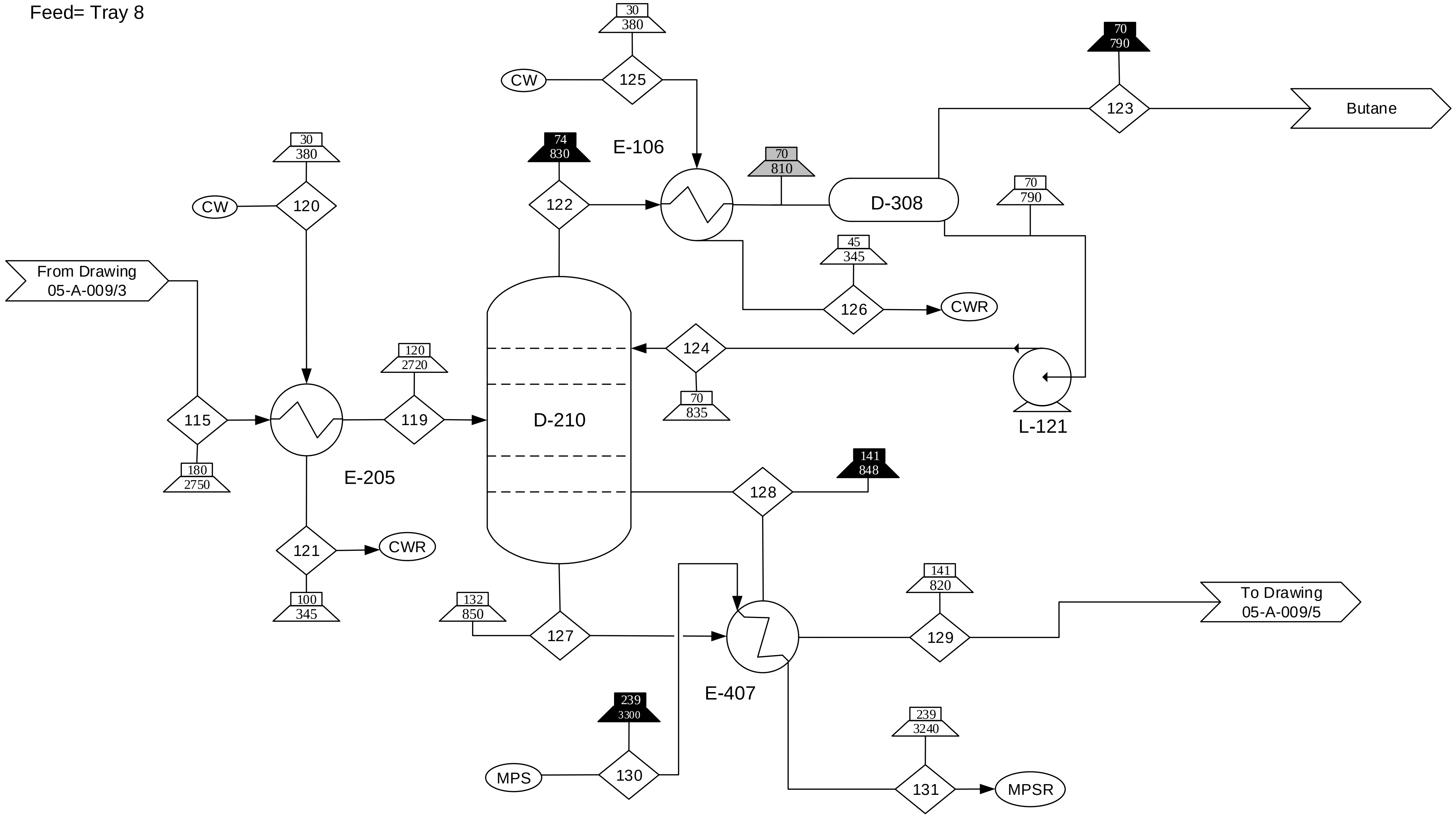
E-205 A/B
Debutanizer Cooler
Area= 7 m^2
Duty= 350 kW

E-106 A/B
Debutanizer Cooler
Area= 57 m^2
Duty= 880 kW

E-407 A/B
Debutanizer Reboiler
Area= 12 m^2
Duty= 1000 kW

D-308
Debutanizer
Reflux Drum
Length= 6.7 m
Diameter= 1.7 m

L-121 A/B
Debutanizer Column Reflux
Power= 3.2 kW

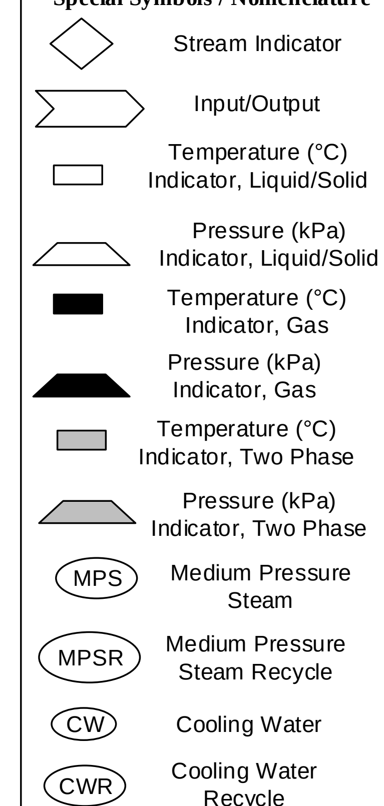


Component/Stream (kg/min)	115	119	120	121	122	123	124	125	126	127	128	129	130	131
C4-C6	86	86	0	0	0	0	0	0	0	0	0	0	0	0
Butane	0	0	0	0	150	22	130	0	0	0	0	0	0	0
C5-C6	0	0	0	0	0	0	0	0	0	230	160	68	0	0
Water	0	0	340	340	0	0	0	820	820	0	0	0	35	35
Total	86	86	340	340	150	22	130	820	820	230	160	68	35	35

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in kg/min.
4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
5. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagram
00-A-007
Block Flow Diagram
00-A-008
Process Flow Diagrams
05-A-009

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-2-17	05-A-009/4	0

D-211
C5 Product Column
Height= 15.8 m
Diameter= 1.1 m
Trays= 17
Feed= Tray 10

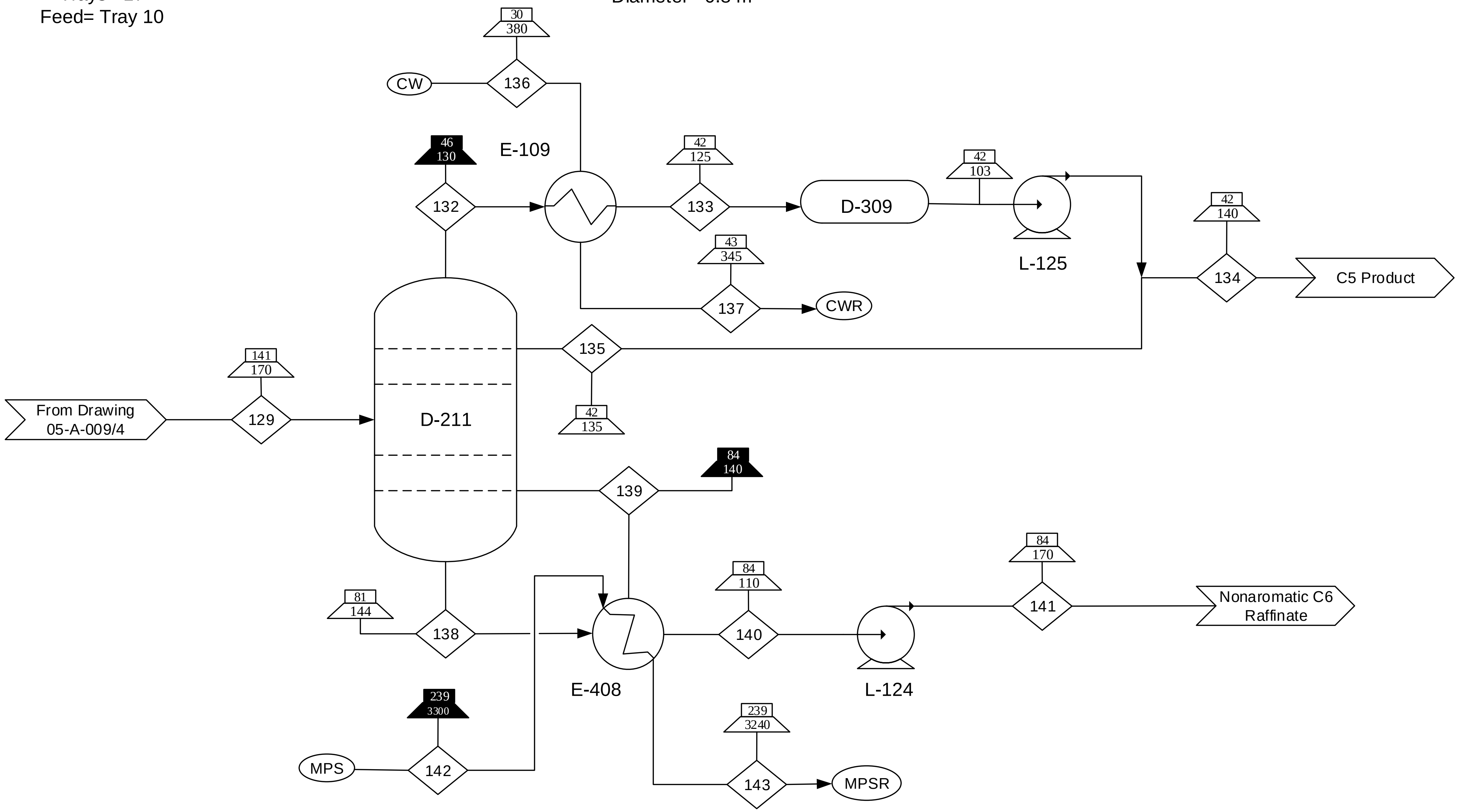
E-109 A/B
C5 Product Condenser
Area= 240 m^2
Duty= 790 kW

E-408 A/B
C5 Product Reboiler
Area= 4 m^2
Duty= 560 kW

D-309
C5 Product Column
Reflux Drum
Length= 3 m
Diameter= 0.8 m

L-125 A/B
C5 Reflux
Power= 2.9 kW

L-124 A/B
C5 Bottoms
Power= 120 W



Component/Stream (kg/min)	129	132	133	134	135	136	137	138	139	140	141	142	143
C5-C6	68	0	0	0	0	0	0	0	0	0	0	0	0
C5 Product	0	100	100	25	80	0	0	0	0	0	0	0	0
Nonaromatic C6 Raffinate	0	0	0	0	0	0	0	79	37	42	42	0	0
Water	0	0	0	0	0	770	770	0	0	0	0	19	19
Total	68	100	100	25	80	770	770	79	37	42	42	19	19

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in kg/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°C) Indicator, Liquid/Solid
Pressure (kPa) Indicator, Liquid/Solid
Temperature (°C) Indicator, Gas
Pressure (kPa) Indicator, Gas
MPS Medium Pressure Steam
MPSR Medium Pressure Steam Recycle
CW Cooling Water
CWR Cooling Water Recycle

Reference Drawings:

Input/Output Diagram
00-A-007
Block Flow Diagram
00-A-008
Process Flow Diagrams
05-A-009

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-3-17	05-A-009/5	0

Appendix B. Under Developed Alternatives

Three additional alternatives were considered besides the three presented in the body of this thesis. These alternatives include processing the heavy ends into anode grade coke, light end processing where LPG is recovered instead of butane, and aromatic reformation of the middle distillates. It was determined that these processes were not going to have sufficient economic value for a full preliminary design and economic assessment to be performed. The following sections describe each alternative.

B.1. Heavy End Processing – Anode Grade Coke Recovery

Previous experimental work performed by Bosquez et. al showed that crop oil tars could be converted into a high grade carbon product. The actual coke that was recovered from the delayed coking process was similar in composition to green coke, and would need to be further calcined for the coke to be sold as anode grade coke, as described in Chapter I.

The base design produced enough vacuum tars that would result in roughly 2000 barrels per day capacity for a delayed coking unit. A representative of British Petroleum was contacted in order to get a budgetary estimate on a delayed coking unit for this size. This representative said that a typical moderately sized delayed coking unit would have the capacity of 15,000-20,000 barrels per day. He recommended that since the unit size required for this design was so small that a custom design would be required. This would in turn result in very high costs, roughly $15 million for the unit alone. This entire conversation can be found in Appendix G.

In addition, a representative from Metso, a Finnish industrial machinery company, was contacted to get a budgetary estimate on a coke calcining unit. The design was capable of producing roughly 27,000 tons per year of calcined coke. The representative relayed that modern plants generally need to product at least 200,000 tons per year to be economical. Also, due to the small capacity, the unit costs would be very high, roughly $24.5 million. The full conversation can be found in Appendix G.

Based on conversations, it was determined that due to the small production of coke, it would not be economically feasible to process the heavy ends into anode grade coke. It would require roughly 10 world scale TAG oil processing plants to produce enough vacuum tars to supply a moderately sized delayed coking and coke calcining facility. For these reasons this alternative was not fully developed.

B.2 Light End Processing – LPG Recovery

The designs presented in the body of this thesis recover butane as a byproduct in the light end processing section of the plant. The propane that is produced during the process is recovered in the syngas stream and burned onsite in the boilers. The alternative of recovering the propane with the butane as a LPG byproduct was also considered.

In order to recover the LPG without using extremely cold temperatures for cryogenic distillation, a lean oil absorption design was considered using Varsol as a solvent. Figure B.1 shows a quasi-block flow diagram of the light end purification section recovering LPG using lean oil absorption.

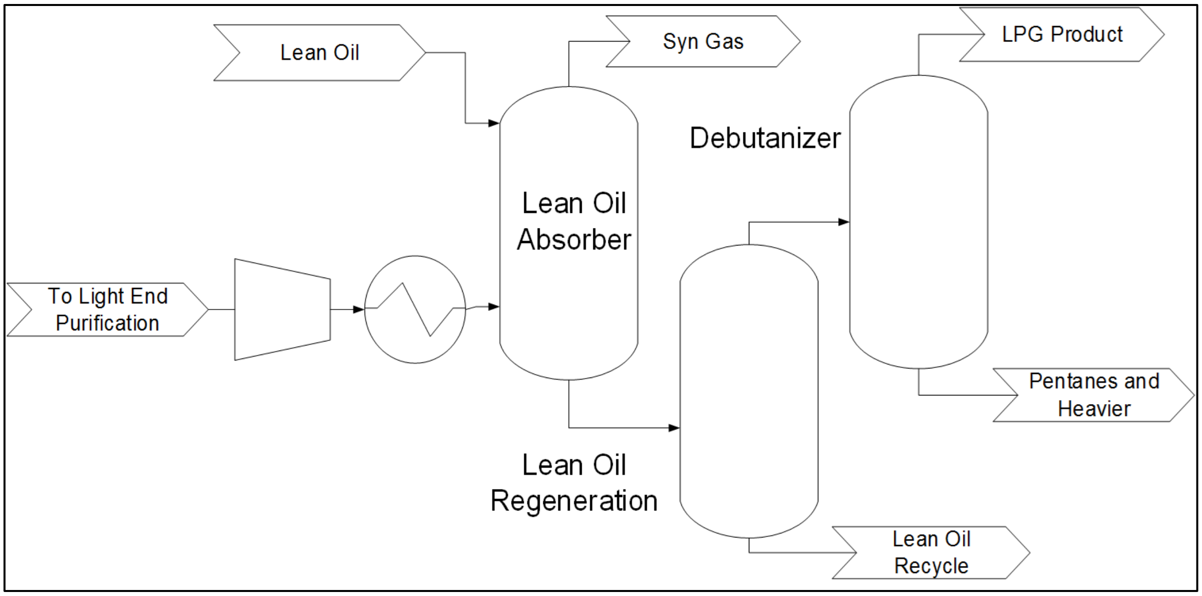


Figure B.1. LPG recovery through lean oil absorption.

The reason this alternative wasn't fully developed was due to the cost of the solvent. In order to remove enough of the CO_2 from the LPG stream, 5000 lb/min of solvent was required. The sale price of Varsol quoted was high enough to make this process economically infeasible. It was determined it would be better to use cryogenic distillation to remove the syngas and carbon dioxide. Further refinement of the light end processing section could result in designs that require less solvent, making this alternative more attractive.

B.3. Aromatic Reformation

Roughly 10-20% of the OLP recovered from the noncatalytic cracking process are medium chain length olefins. These olefins need to be removed or converted prior to sale, as they are undesirable for fuel applications. One way to recover these olefins is by reforming them into aromatic compounds. This produces a saleable byproducts of aromatics in the C6-C12 range. This alternative process was described in Chapter I. Figure B.2 displays a quasi-block flow diagram of the aromatic reformation plant design.

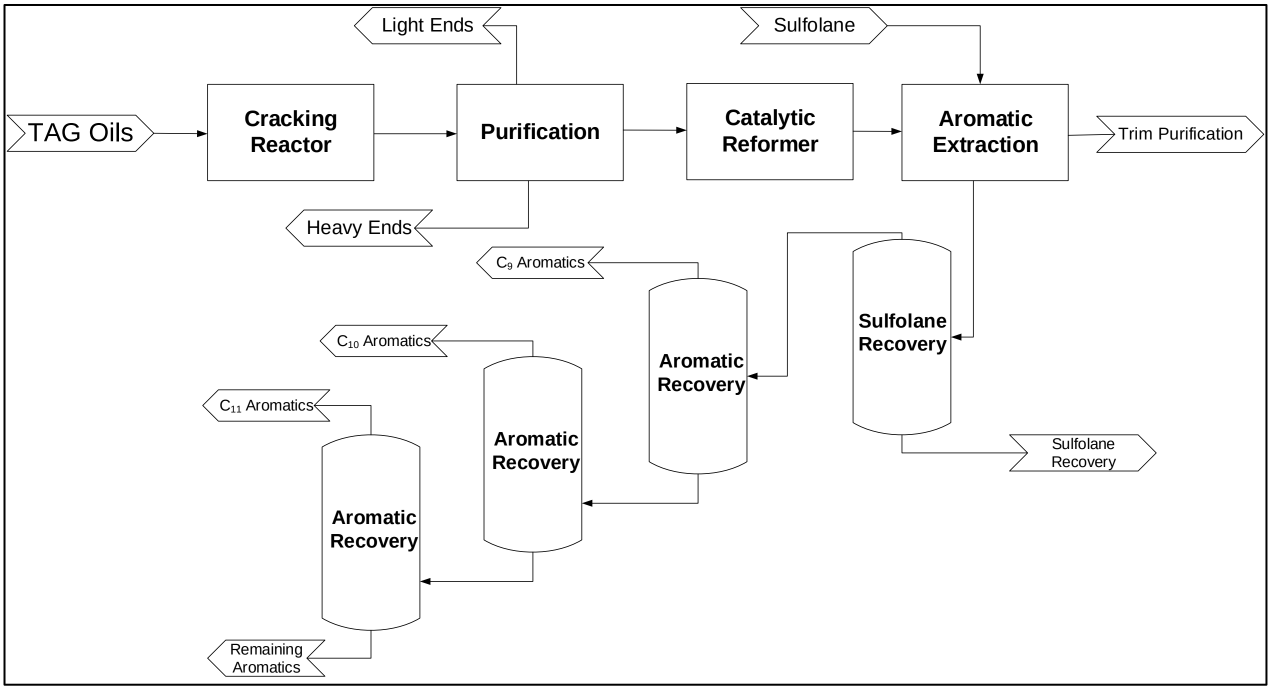


Figure B.2. Aromatic reformation alternative design.

The problem that arises from this alternative is the low yield of aromatics from inlet carbon. Roughly 32% of the inlet carbons are converted to the aromatic byproducts. For this reason this alternative was not developed on a preliminary design level. Further development of the process would need to be performed to maximize the aromatic yields before this alternative can be developed.

Appendix C. Intermediate Results

C.1. Heat Transfer Coefficients

The following table shows the heat transfer coefficients used to determine the area required for heat exchangers and reactors. The U values were obtained from Chemical Engineers' Handbook, fifth edition [48].

Table C.1. Overall Heat Transfer Coefficients

Equipment Number	**Equipment Description**	**"U" (Btu/hr-ft^2-°F)**
R-101	TTCR	52.8
E-201	Post Cracking Cooler	50
E-202	Flash 2 Cooler	75
E-101	Atmospheric Column Condenser	150
E-102	Vacuum Column Condenser	150
E-103	Jet Diesel Cut Condenser	75
E-204	Light End Cooler	75
E-205	Debutanizer Cooler	75
E-104	Light End Condenser	90
E-105	Naphtha Jet Condenser	80
E-106	Debutanizer Condenser	90
E-107	Diesel-Fuel Oil Cut Condenser	150
E-108	Hexane Splitter Condenser	85
E-207	Pre-Flash 5 Cooler	90
E-208	Post Diesel Decarboxy Cooler	150
E-209	Post Naphtha Decarbox Cooler	150
E-210	Inter stage Cooler 1	80
E-211	Inter stage Cooler 2	80
E-109	C5 Product Condenser	80
E-212	Naphtha Cooler	80
E-213	Jet Cooler	65
E-214	Diesel Cooler	150
E-215	Fuel Oil Cooler	150
E-502	TTCR Preheat	60
E-401	Atmospheric Column Reboiler	95
E-402	Vacuum Column Reboiler	60
E-503	Naphtha Decarbox Heater	95
E-504	Diesel Decarbox Heater	85
E-505	Pre Jet Diesel Cut Heat	85
E-403	Naphtha Jet Cut Reboiler	95
E-404	Jet Diesel Cut Reboiler	60
E-405	Cryogenic Reboiler	150
E-406	Hexane Splitter Reboiler	70
E-407	Debutanizer Reboiler	150

(continued)

Table C.1. Cont.

Equipment Number	Equipment Description	"U" (Btu/hr-ft^2-°F)
E-408	C5 Product Reboiler	150
E-409	Diesel Fuel Oil Cut Reboiler	80
E-701	Post Cracking Cooler	50
E-702	Flash 2 Cooler	75
E-601	Atmospheric Condenser	75
E-602	Vacuum Column Condenser	150
E-703	Pre Flash 3 Cooler	50
E-603	Hexane Splitter Condenser	50
E-604	Naphtha Jet Cut Condenser	50
E-605	Jet Diesel Cut Condenser	150
E-606	Diesel Fuel Oil Cut	150
E-704	Syngas Cooler	75
E-705	Stage 1 Cooler	50
E-706	Stage 2 Cooler	75
E-607	Syngas Condenser	50
E-707	Debutanizer Cooler	75
E-608	Debutanizer Condenser	50
E-609	Water Removal Condenser	50
E-610	C2-C4 Split Condenser	50
E-611	Acetic Acid Condenser	50
E-708	C6-C7 Cooler	75
E-612	C6-C7 Condenser	75
E-709	C4-C5 Cooler	75
E-613	C4-C5 Condenser	50
E-614	C3-C4 Condenser	50
E-615	C5-C6 Condenser	75
E-710	C8-C9 Cooler	150
E-616	C8-C9 Condenser	75
E-617	C7-C8 Condenser	75
E-711	C10-C11 Cooler	150
E-618	C10-C11 Condenser	75
E-619	C9-C10 Condenser	75
E-620	C11 Condenser	75
E-712	C11 Cooler	150
E-713	Flash 4 Cooler	150
E-714	Pre Jet Diesel Cut Cooler	75
E-902	Vacuum Column Reboiler	60
E-801	TTCR Preheat	60
E-901	Atmospheric Column Reboiler	95
E-903	Jet Diesel Cut Reboiler	60
E-904	Hexane Splitter Column	70
E-905	Naphtha Jet Reboiler	95
E-906	Diesel Fuel Oil Cut Reboiler	80
E-907	Syngas Column Reboiler	150
E-908	Debutanizer Reboiler	150

(continued)

Table C.1. Cont.

Equipment Number	Equipment Description	"U" (Btu/hr-ft^2-°F)
E-802	Atmospheric Column Preheat	95
E-909	Water Removal Reboiler	95
E-910	C2-C4 Column Reboiler	95
E-911	Acetic Acid Column Reboiler	95
E-920	C11 Reboiler	95
E-919	C9-C10 Reboiler	95
E-918	C10-C11 Reboiler	95
E-917	C7-C8 Reboiler	95
E-916	C8-C9 Reboiler	95
E-915	C5-C6 Product	95
E-914	C3-C4 Reboiler	95
E-803	C3-C4 Heater	95
E-912	C6-C7 Reboiler	95
E-913	C4-C5 Reboiler	95
E-804	Fatty Acid Decarbox Heater	95
E-1001	Naphtha Cooler	50
E-1002	Jet Cooler	75
E-1003	Diesel Cooler 1	150
E-1004	Diesel Cooler 2	50
E-1005	Fuel Oil Cooler	50
E-506	Pitching Preheat	450
E-1101	Jet Cooler	75
E-1102	Diesel Cooler	150
E-1103	Fuel Oil Cooler 1	50
E-1104	Fuel Oil Cooler 2	150

C.2. Revenue Calculations

The following equations were used to calculate the annual revenue for the process. Shipping costs were not considered while performing calculations [51].

$$R_i = \ Amount * SP_i$$
$$R_{total} = (O_F * \Sigma R_i)$$

Where:
R_i= Revenue of Commodity i
R_{total}= Total revenue
O_F= Operating factor
S_i= Selling price of commodity i

The calculation for revenue was based on a 95% operating factor. The numbers presented below may be off due to rounding.

Revenue From Jet Fuel:

$$\left(437\,\frac{lb}{min}\right) * \left(60\,\frac{min}{hr}\right) * \left(24\,\frac{hr}{day}\right) * \left(365\,\frac{day}{year}\right) * \left(\frac{1\,ft^3}{46.65\,lb}\right) * \left(\frac{264.17\,gallons}{35.3145\,ft^3}\right) * \left(\frac{\$1.299}{gallon}\right) * 0.95 = \$48{,}800{,}000/year$$

Revenue From Diesel Fuel no 2:

$$\left(471\,\frac{lb}{min}\right) * \left(60\,\frac{min}{hr}\right) * \left(24\,\frac{hr}{day}\right) * \left(365\,\frac{day}{year}\right) * \left(\frac{1\,ft^3}{48.93\,lb}\right) * \left(\frac{264.17\,gallons}{35.3145\,ft^3}\right) * \left(\frac{\$1.378}{gallon}\right) * 0.95 = \$51{,}000{,}000/year$$

Revenue From Petroleum Naphtha:

$$\left(148\,\frac{lb}{min}\right) * \left(60\,\frac{min}{hr}\right) * \left(24\,\frac{hr}{day}\right) * \left(365\,\frac{day}{year}\right) * \left(\frac{1\,ft^3}{43.07\,lb}\right) * \left(\frac{264.17\,gallons}{35.3145\,ft^3}\right) * \left(\frac{\$1.30}{gallon}\right) * 0.95 = \$17{,}300{,}000/year$$

Revenue From Butane:

$$\left(48\,\frac{lb}{min}\right) * \left(60\,\frac{min}{hr}\right) * \left(24\,\frac{hr}{day}\right) * \left(365\,\frac{day}{year}\right) * \left(36.03\,\frac{lb}{ft^3}\right) * \left(\frac{264.17\,gallons}{35.3145\,ft^3}\right) * \left(\frac{\$0.61}{gallon}\right) * 0.95 = \$3{,}000{,}000/year$$

Revenue From Vacuum Bottoms:

$$\left(617\,\frac{lb}{min}\right) * \left(60\,\frac{min}{hr}\right) * \left(24\,\frac{hr}{day}\right) * \left(365\,\frac{day}{year}\right) * \left(\frac{\$0.05}{lb}\right) * 0.95 = \$15{,}400{,}000/year$$

Revenue From C5 Product:

$$\left(141{,}000\,\frac{bbl}{year}\right) * \left(\frac{\$36.61}{barrel}\right) * 0.95 = \$5{,}200{,}000/year$$

Revenue From Non-Aromatic Raffinate:

$$\left(233{,}000\,\frac{bbl}{year}\right)*\left(\frac{\$36.61}{barrel}\right)*0.95=\$850{,}000/year$$

Revenue from Mesophae pitch

$$\left(216\,\frac{lb}{min}\right)*\left(\frac{0.453593\;kg}{1\;lb}\right)*\left(60\,\frac{min}{hr}\right)*\left(24\,\frac{hr}{day}\right)*\left(365\,\frac{day}{year}\right)*\left(\frac{\$15.0}{kg}\right)*0.95$$
$$=\$730{,}000{,}000/year$$

Revenue From Acetic Acid:

$$\left(9.73\,\frac{lb}{min}\right)*\left(60\,\frac{min}{hr}\right)*\left(24\,\frac{hr}{day}\right)*\left(365\,\frac{day}{year}\right)*\left(\frac{\$0.5}{lb}\right)*0.95=\$2{,}400{,}000/year$$

Total Revenue = $48,800,000 + $51,000,000 + $17,300,000 + $3,000,000 + $5,200,000 + $850,000 + $2,400,000 = $144,000,000/year

For the fatty acid recovery most of the above products will be produced. In addition to the transportation fuels, fatty acids will also be sold as a byproduct. Below is an example equation as to how the fatty acid revenue was calculated.

$$Revenue=m*\left(\frac{\$\;Price}{lb}\right)*0.95$$

Where:
m = Mass flow rate of acid produced (lb/year)

C.3. Depreciation

The MACRS method was used in depreciation calculations. The method combines both the double declining balance (DDB) and the straight line depreciation method. The first half of the project’s lifespan is depreciated by the DDB. The remaining years of the project’s lifespan are depreciated by the straight line method. The following table has the calculated MACRS factors for depreciation over 17 years. For project assessment purposes, the full year MACRS method was used, rather than the ½ year method often employed in accounting calculations [51].

Depreciation during first nine years:

$$d_t = \frac{2}{N}\left(FCI - \sum_{i=1}^{t} d_i\right) = \frac{2}{10}(100 - 0) * 100\% = 20\%$$

Where:

d_t = depreciation in year t ($)
N = total number of years for depreciation

Depreciation during last eight years:

$$d_T = \frac{2}{N}(FCI - Cumulative\ Depreciation)$$

Where:

d_t = depreciation in year t ($)
N = total number of years for depreciation

Table C.2. MACRS Factors Used in Depreciation Calculations

Year	MACRS Factor (% Depreciation)
1	11.7
2	10.4
3	9.2
4	8.1
5	7.1
6	6.3
7	5.6
8	4.9
9	4.3
10	4.1
11	4.1
12	4.1
13	4.1
14	4.1
15	4.1
16	4.1
17	4.1

C.4. Labor Costs

According to rules of thumb, one new outside operator is required per shift per 5 major unit operations [51]. Additionally, one new outside operator is added every 20 minor unit operations. The rule of thumb that 4.5 shifts a week covers continuous operation was used to determine the total number of operators needed. The example below shows that the equivalent of 22 major unit operations are needed for the process. This equates to 27 new outside operators to cover 24/7 operation. An additional 4.5 operators are added to this value to account for board operators, which adds to a total of 32 operators needed. Operator salaries were found from the Workforce Intelligence Network quarterly review [53].

Total Operating Labor = ($62,800 * 32)*1.15 = $2,200,000/year

C.5. Raw Material Cost Calculation

The raw material required for the process was assumed to be soybean oil, although any triglyceride or fatty acid based oil can be used. Soybean oil was chosen as it has the highest rate of production. The price of soybean oil was calculated from price trends over the past 5 years, found in Chapter I of this thesis.

$$\left(2{,}200\,\frac{lb}{min}\right)*\left(\frac{\$0.30}{lb}\right)*\left(\frac{24\ hour}{day}\right)*\left(\frac{365\ days}{year}\right)*\ 0.95=\$330{,}000{,}000/year$$

C.6. Chemicals and Catalyst Price Calculation

The cost of the chemicals and catalysts were calculated from values obtained from vendors. These products included the TMA, nitrogen, and the catalyst Ni/SiO_2 55. The below values may be off due to rounding. It was assumed that there was a 17% loss of solvent per year, and a 4% loss of catalyst. In addition to the 4% replenishment of catalyst, the entire amount of catalyst must be replaced every 4 years [51].

Cost of Nitrogen:

$$Cost\ per\ year=\left(\frac{\$11{,}700}{month}\right)*\frac{12\ months}{year}*0.95=\$130{,}000/year$$

Cost of Ni/SiO_2 55:

$$Initial\ Cost = 18700\ ft^3 * \frac{\$1000}{ft^3} = \$19{,}000{,}000$$

$$Replacement\ Cost = 18700\ ft^3 * 0.04 * \frac{\$1000}{ft^3} = \$750{,}000$$

Cost of TMA:

$$Initial\ Cost = \ 30{,}600\ lb * \frac{\$16.50}{lb} = \$500{,}000$$

$$Replacement\ Cost = \ 30{,}600\ lb * 0.17 * \frac{\$16.50}{lb} = \$86{,}000$$

C.7. Utility Cost Calculation

The cost of utilities were calculated using the Turton cost estimation method [54]. Utilities included were the cost of boiler feed water, cooling water, electricity, refrigerant, process water, and waste water treatment. The below values may be off due to rounding.

$$Cost\ per\ year = C_u * Amount * 0.95$$

Where:
C_u = Cost of the utility

Cost of Boiler Feed Water:

$$Cost\ per\ year = \frac{\$0.59}{1000kg} * \frac{11{,}100{,}000{,}000kg}{year} * 0.95 = \$6{,}200{,}000/year$$

Cost of Cooling Water:

$$Cost\ per\ year = \frac{\$14.8}{1000m^3} * \frac{6{,}800{,}000m^3}{year} * 0.95 = \$96{,}000/year$$

Cost of Electricity:

$$Cost\ per\ year = \frac{\$0.06}{kWy} * 34{,}400{,}000kWy * 0.95 = \$2{,}000{,}000/year$$

Cost of Refrigeration:

$$Cost\ per\ year = \frac{\$0.55}{1000kg} * \frac{290{,}000{,}000kg}{year} * 0.95 = \$150{,}000/year$$

Cost of Process Steam:

$$Cost\ per\ year = \frac{\$0.067}{1000kg} * \frac{12{,}400{,}000kg}{year} * 0.95 = \$800/year$$

Cost of Natural gas:

$$Cost\ per\ year = \frac{\$5.60}{1000ft^3} * \frac{80{,}500{,}000\ ft^3}{year} * 0.95 = \$300{,}000/year$$

Total Utility Cost:

$$Cost\ per\ year = \$6{,}200{,}000 + \$96{,}000 + \$2{,}000{,}000 + \$150{,}000 + \$800 + \$300{,}000 = \$8{,}700{,}000/year$$

C.8. Tax Calculations

A federal tax rate of 35% and a Minnesota state tax rate of 9.8% were used for tax calculations. The blended tax rate that was used was calculated from the following equations [51].

(100%- Effective Federal tax rate) * State tax rate = Effective State rate

(100%-35%) * 9.8% = 0.65*0.098 = 6.37%

Effective Federal Rate + Effective State rate = Blended (state and federal) rate

35% Effective Federal rate + 6.37% Effective State rate = 41% Blended rate

Appendix D. Sample Calculations

D.1. Heat Exchanger Sizing

The required area of a heat exchanger can be calculated by using the overall heat transfer coefficient, the heat duty, the inlet and outlet temperature of the process fluid, and the inlet and outlet temperature of the utility fluid. All heat exchangers sized in this project were single pass, counter flow. Reboilers were sized/designed as thermosiphon reboilers, and the remaining exchangers were designed as shell and tube heat exchangers and priced as floating head shell and tube heat exchangers [65]. All heat exchangers were designed assuming an 80% efficiency, and the overall heat transfer coefficients were found using The Chemical Engineers Handbook, fifth edition, and provided in Table C.1.

$$A = \frac{Q}{U * \Delta T_L}$$

$$\Delta T_L = \frac{(T_1 - t_2) - (T_2 - t_1)}{ln\frac{(T_1 - t_2)}{(T_2 - t_1)}}$$

$$A = \frac{2796534\,Btu/hr}{80\frac{Btu}{hr * ft^2 * ºF} * \frac{-1 * ((125ºF - 86ºF) - (287ºF - 113ºF))}{ln\frac{(125ºF - 86ºF)}{(287ºF - 113ºF)}}} = 390\,ft^2$$

Where:
Q = Heat duty of the exchanger accounting for 80% efficiency (Btu/hr)
A = Surface area of heat exchanger (ft^2)
T1 = Temperature of hot fluid in (°F)
T2 = Temperature of hot fluid out (°F)
t1 = Temperature of cold fluid in (°F)
t2 = Temperature of cold fluid out (°F)
U = Overall heat transfer coefficient (BTU/(hr ft^2 °F))

D.2. Flowrate of Cooling Water/Heating Steam

The required flow rate of the utility fluid was found from the heat duty of the heat exchanger, and the enthalpy change of the utility fluid. The enthalpies of the steam and water flowing through the exchangers were found from the Introduction to Chemical Engineering Thermodynamics.

$$m = \frac{Q}{\Delta H} * \frac{1}{60}$$

$$\Delta H = H_{Cold} - H_{Hot}$$

$$m = \frac{2796534\ Btu/hr}{6817.092 \frac{Btu}{lbm} - \frac{6790.1 Btu}{lbm}} * \frac{1hr}{60\ min} = 1730\ lb/min$$

Where:
Q = Heat duty of the exchanger accounting for 80% efficiency (Btu/hr)
H_{cold} = Enthalpy of the cold utility stream (Btu/lbm)
H_{Hot} = Enthalpy of the hot utility stream (Btu/lbm)

D.3. Column Diameter

The diameter of the distillation columns in the project were calculated through a multi-step process [46]. The diameter of the column was based off of the stage with the largest flow rate associated with it. This was usually the second to last stage in the column. First, the density of the vapor flow in the column was calculated.

$$\rho_V = \frac{P(MW)}{RT}$$

Where:
ρ_V = Density of vapor (lb/ft^3)
P = Pressure (atm)
MW = Molecular weight (lb/lbmol)
R = Gas Constant (psia*ft^3/lbmol*R)
T = Temperature (K)

Using the density of the vapor and liquid in the column, as well as the mass flow rates of the vapors and liquids, a flow parameter could be calculated. This flow parameter was then used on Figure 10-16 in Separation Process Engineering [46] to find the capacity factor, C_{sb}.

$$F_{lv} = \frac{W_l}{W_v}\sqrt{\frac{\rho_v}{\rho_l}}$$

Where:
F_{lv} = Flow Parameter
W_l = Mass flow rate for liquid (lb/hr)
W_v = Mass flow rate for vapor (lb/hr)
ρ_l = Density of liquid (lb/ft^3)

$$K = C_{sb,f}(\frac{\sigma}{20})^{0.2}$$

Where:
K = Empirical constant
$C_{sb,f}$ = Capacity factor (obtained from figure 10-16) [12]
σ = Surface tension (dynes/cm)

$$u_{flood} = K\sqrt{\frac{\rho_l - \rho_v}{\rho_v}}$$

Once the flooding velocity was obtained, the diameter of the column could be calculated using the flooding velocity, vapor flow rate, temperature and pressure of the column, the fraction of the column available for vapor flow, and the flooding fraction.

Where:
u_{flood} = Flooding velocity (ft/s)

$$D = \sqrt{\frac{4VRT}{\pi\eta(3600)P(\gamma)u_{flood}}}$$

Where:
D = Column diameter (ft)
V = Vapor flow rate (largest in column) (ft^3/s)
η = Fraction of column cross-sectional area that is available for vapor flow (assumed to be 0.9)
γ = Flooding fraction (assumed to be 0.8)

$$\rho_V = \frac{(4\,psia)\,(274)}{\left(10.73\,\frac{ft^3psia}{lb-mol°R}\right)(1082\,°R)} = 0.109\,(\frac{lb}{ft3})$$

$$F_{lv} = \frac{2225\,\frac{lb}{hr}}{1678\,\frac{lb}{hr}}\sqrt{\frac{0.109\,\frac{lb}{ft^3}}{40.97\,\frac{lb}{ft^3}}} = 0.06$$

$$K = 0.06\left(\frac{9.87\frac{dyne}{cm}}{20}\right)^{0.2} = 0.395\frac{ft}{s}$$

$$u_{flood} = 0.395\frac{ft}{s}\sqrt{\frac{40.97\frac{lb}{ft^3} - 0.109\frac{lb}{ft^3}}{0.109\frac{lb}{ft^3}}} = 6.64\frac{ft}{s}$$

$$D = \sqrt{\frac{(4)\left(424\frac{ft^3}{s}\right)\left(10.73\frac{ft^3 * psia}{lb - mol * °R}\right)(1082°R)}{(3.14)(0.8)(3600)(4psia)(0.9)\left(6.64\frac{ft}{s}\right)}} = 9.5\,ft$$

D.4. Column Height

Assuming a tray efficiency of 70%, and using the assumed tray spacing of 1-2 ft, the height of the column can be calculated from the number of trays. The tray spacing was determined on a column to column basis, with smaller columns have only a 1 ft tray space, and larger ones having a 2 ft tray space. A column's diameters worth of height was added to the bottom of the column to account for the liquid hold-up, and a column diameters worth was also added to the top of the column to account for vapor-liquid disengagement. [46].

$$H = \frac{(N * S) + 2D}{\delta}$$

$$H = \frac{(20 * 2ft) + (2 * 9.5ft)}{0.7} = 77\,ft$$

Where:
N = Number of trays
S = Space between trays (ft)
δ = Tray efficiency
D = Column diameter worth of height (ft)

D.5. Reflux Drums

Reflux drums were designed to have a 5 min liquid residence time, horizontal in shape, and a length to diameter ratio of 4. For partial condensers, the 5 min liquid residence time was assumed to fill the drum to 50%. All sizes were rounded up to the nearest half foot. The reflux drum was sized to ensure it met the required volume of fluid. First, the required volume of the reflux drum was found [47].

$$Q = \frac{D * (1 + R)}{\rho}$$

Where:
Q = Volumetric flow rate (ft3/min)
D = Distillate flow rate (lb/min)
R = Reflux ratio
ρ = Density (lb/ft3)

From the volumetric flow rate through the drum, and a known residence time of 5 min, the required volume can be found.

$$V_R = Q * 5$$

Where:
V_R = Required volume of drum (ft3)

Once the required volume was known, the dimensions of the flash drum were found through trial and error assuming a length to diameter ratio of 4. The diameter of the drum was found from the below equation, and then the length could be found by being four times that of the diameter.

$$V = \pi * \left(\frac{D}{2}\right)^2 * 4D$$

Where:
V = Volume of drum (ft3)
D = Diameter of drum (ft)

$$Q = \frac{\left(375\frac{lb}{min}\right) * (1 + 0.1)}{46.62\frac{lb}{ft^3}} = 8.83\ \frac{ft^3}{min}$$

$$V_R = 8.83\frac{ft^3}{min} * 5min = 44.2\ ft^3$$

$$V = \pi * \left(\frac{2.5ft}{2}\right)^2 * 10ft = 50ft^3$$

D.6. Turbulent Tubular Cracking Reactor (Size specs and Steam Requirement)

The TTCR was designed around the desired specifications found from previously collected data [10]. This required a residence time of 1.17 hours. The data was tested in a pilot scale reactor, so this reactor was then just scaled up to the desired specifications. It was assumed that ½ inch ID tubes would be used for the tube size, and a 1.25 triangular pitch space was used for inside the tubing [65]. It was also assumed that the log mean temperature difference within the reactor could not exceed 8F, and the heat transfer coefficient was found from Ulrich. The size of the reactor was calculated from finding the total number of tubes needed, and then from there what the length and the diameter of the reactor would be [10]. First, the volume of one tube with a ½ inch ID and 80 ft long is.

$$V = \pi * r^2 * L * \left(\frac{1000}{10^6}\right)$$

Where:
V = Volume of tube (L)
R = Radius of tube (cm)
L= length of tube (cm)

Once the volume of one tube was known, the total amount of tubes needed was calculated from the known residence time.

$$N = \frac{Q * \tau}{V}$$

Where:
N= Number of tubes
Q= Volumetric flow rate (L/hr)

V= Volume (L)
τ = Residence time (hr)

Once the number of tubes needed was known, the reactor diameter could be found from the known tube OD, and the needed pitch space of 1.25 in between tubes.

$$D = N * 1.25 * OD$$

Where:
D= Diameter of reactor (ft)
OD = Outer diameter of tubes (in)

Due to the length of the reactor, it was designed to be a U shaped reactor, 40ft long with a total diameter of 20 ft.

The steam required to heat the TTCR was calculated from the required heat duty. This heat duty was found from adding the heat of reaction (endothermic reaction) and the heat required to increase the feed temperature from 770F to 806F.

$$Q = (H_R * m) + (m * C_p * \Delta T)$$

Where:
Q = Heat duty of the reactor (Btu/min)
H_R = Heat of the reaction (KJ/kg)
m = Mass flow rate of soybean oil (lb/min)
C_p = Heat capacity of soybean oil (cal/g*C)
ΔT = Change in temperature of soybean oil (°C)

Once the required heat duty for the reactor was found, the surface area needed for the steam to heat the soybean oil was calculated.

$$A = \frac{Q}{U * \left(\frac{1}{60}\right) * \Delta T_{LM}}$$

Where:
A = Surface area required for heat transfer (ft2)
Q = Heat duty (Btu/min)
U = Overall heat transfer coefficient (Btu/hr*F*ft2)
ΔT_{LM}= Log mean temperature difference (°F)

This area was then compared to the surface area available from the tubes, to ensure that there was enough surface area available to use steam as the heating fluid. The surface area of the tubes was found from the number of tubes, length, and outer diameter.

$$SA = 2 * \pi * \frac{OD}{2} * L * N$$

Where:
SA= Surface area of tubes (ft2)
OD = Outter diameter of tubes (cm)
L=Length of tubes (cm)
N= Total number of tubes

The available surface area was then known to be greater than the surface area needed for the steam, so the amount of heating steam needed was then calculated. It was assumed that the boiler would be able to produce superheated steam available at 815 °F and 875 psia. With a known log mean temperature difference of 8°F, the outlet temperature of the steam was determined to be 777 °F. Once these temperatures were known, the enthalpy of the hot and cold superheated steam was found from the Introduction to Chemical Engineering Thermodynamics. The mass flow rate of the steam needed was then calculated.

$$m_s = \frac{Q}{\Delta H_{Steam}}$$

$$\Delta H_{Steam} = H_{SH} - H_{SC}$$

Where:
m_S = Mass flow rate of steam needed (lb/min)
Q = Heat duty (Btu/min)
H_{SH} = Enthalpy of hot steam (Btu/lbm)
H_{SC}= Enthalpy of cold steam (Btu/lbm)

$$V = \pi * (0.695cm)^2 * 2448cm * \frac{1000}{10^6} = 3.71L$$

$$N = \frac{65346\frac{L}{hr} * 1.17hr}{3.71L} = 20582\ tubes$$

$$D = 20582 * 1.25 * 0.8385in * \left(\frac{1}{12}\right) = 14\ ft$$

$$Q = (428kJ/kg * 2200lb/min * \left(\frac{1kg}{2.20462lb}\right) * 1000J/kJ * 0.0009486Btu/J) + (2200lb/min * \left(\frac{1kg}{2.20462lb}\right) * 1000g/kg * \left(\frac{1Btu}{0.239cal}\right) * 0.744cal/g°C * 2.22°C) = 411698\ \text{Btu/min}$$

$$A = \frac{411698Btu/min}{52.8\frac{Btu}{hr * °F * ft^2} * \left(\frac{1\ hr}{60min}\right) * 8°F} = 58480\ ft^2$$

$$SA = 2 * \pi * \frac{2.13cm}{2} * 2448cm * 20582 * \left(\frac{1in^2}{(2.54cm)^2}\right) * \left(\frac{1ft^2}{(12in)^2}\right) = 362903\ ft^2$$

$$m_s = \frac{411698Btu/min}{1403.497Btu/lb - 1381.054Btu/lb} = 18344\ lb/min$$

D.7. Decarboxylation Reactor Sizing

The size of the decarboxylation reactors needed were scaled up from the initial testing of decarboxylation in order to fit the required amount of catalyst [10].

$$M_{Catalyst} = m_{Inlet} * Catalyst\ to\ flow\ Ratio$$

Where:
$M_{Catalyst}$ = Mass of catalyst required (kg)
m_{inlet} = Inlet flow through reactor (g/min)
Ratio = Catalyst to flow rate ratio used in initial decarboxylation testing (kg/g/min)

Once the mass of the catalyst was found, the volume of the catalyst was calculated from the known density.

$$V_{Catalyst} = \frac{M_{Catalyst}}{\rho}$$

Where:
$V_{Catalyst}$ = Volume of catalyst (m3)
ρ = Density of catalyst (kg/m3)

The dimensions of the reactors were then calculated to be large enough to cover half of the required catalyst. This is because we will be running two reactors in parallel instead of one large reactor. A diameter to length ratio of 6 was used when calculating the dimensions of the reactor.

$$V_{Reactor} = \pi * \left(\frac{D}{2}\right)^2 * L$$

Where:
$V_{Reactor}$ = Volume of the reactor (ft3)
D= Diameter of reactor (ft)
L= Length of reactor (ft)

$$M_{Catalyst} = 488970 kg/min * 0.98 = 479190\ kg$$

$$V_{Catalyst} = \frac{479190 kg/min}{1000 \frac{kg}{m^3}} = 480\ m^3$$

$$V_{Reactor} = \pi * \left(\frac{12ft}{2}\right)^2 * 73ft = 8460\ ft^3$$

D.8. Energy of Byproduct Steams Available for Boiler Fuel

The amount of energy available from the residual fuel oil stream, syn gas stream, and pentane and heavier stream was calculated. This was used to determine how many of the streams would be needed to be used as a fuel source for the 4 furnaces designed for the plant. The available heat was calculated from the net heating value of the stream and the mass flow rate of that stream.

$$Q = m * LHV$$

$$Q = \left(\frac{419lb}{\text{min}}\right) * \left(\frac{5515Btu}{lb}\right) = 2312740\ \frac{Btu}{min}$$

Where:
Q= Heat available (Btu/min)
m= Mass flow rate of stream (lb/min)
LHV = Lower heating value of stream (net heating value) (Btu/lb)

D.9. Flame Temperature of Furnace Fuels

The flame temperature of the syngas was calculated to ensure it would burn hot enough to be used as a fuel source for the furnaces. The flame temperature was found from the enthalpy of the reaction, and a blended heat capacity of the reactants and products. It was assumed that the fuel source would be burned with 20% excess oxygen, and that the reaction proceeded 90% to completion (formation of CO_2), with 10% of the reactants reacting to CO [49].

The heat of reaction was found from summing the heats of formation of the products and reactants.

$$\Delta H_{298} = \sum \nu_i H_i$$

Where:
ΔH_{298}= Heat of reaction at 298K (J)
ν_i = Stoichiometric number of reactant/product (mol)
H_i= Heat of formation of reactant/product (J/mol)

The heat capacity used for the reaction was found from summing the heat capacities of the products and reactants.

$$\Delta C_P = \sum \nu_i C_{Pi}$$

Where:
ΔC_P= Heat capacity for reaction (Btu/lb-F)
ν_i = Stoichiometric number of reactant/product (mol)
C_{Pi} = Molar heat capacity of reactant/product (Btu/lb-F-mol)

Once the heat capacity and heat of reaction were known, the flame temperature resulting from burning the fuel in air was calculated.

$$T = 77 - \frac{\Delta H_{298}}{C_p * m}$$

$$T = 77 - \frac{-1023240\text{Btu}}{\left(0.2275 \frac{Btu}{lb - \text{°F}}\right) * 832lb} = 5000\ °F$$

Where:
T = Flame temperature (F)
ΔH_{298}= Heat of reaction at 298K (Btu)
C_p= Heat capacity (Btu/lb-F)
m = Mass flow rate of stream (lb)

D.10. Knock Out Drums

The velocity of the gas before the knockout drum was assumed to be 70 ft/s, and reduced to 7 ft/s inside the knock out drum. With this known, the cross sectional area of the drum was then calculated [47].

$$A = \frac{Q}{v}$$

Where:
A = Cross sectional area (ft2)
Q = Volumetric flow rate (ft3/s)
v = velocity (ft/s)

From the cross sectional area the diameter required for the drum was then calculated, and the height was found from a height to diameter ratio of 3.

$$D = \sqrt{\frac{4 * A}{\pi}}$$

$$H = 3 * D$$

Where:
D = Diameter of drum (ft)
H= Height of drum (ft)

$$A = \frac{2.02 \frac{ft^3}{s}}{7 \frac{ft}{s}} = 0.3\ ft^2$$

$$D = \sqrt{\frac{4 * 0.3 ft^2}{\pi}} = 0.6\ ft$$

$$H = 3 * 0.6 ft = 1.8\ ft$$

D.11. Solvent Extractor and Pitching Reactor Sizing

The solvent extractor and pitching reactor were sized based on the known volumetric flow rates flowing through the reactor, and the residence time needed [38]. First the desired volume needed was calculated based on the assumption that there should be 15% extra space in the vessel when it is entirely full for the extractor, and completely full for the reactor [47].

$$V = 1.15 * (q * t_r)$$

$$V = 1.15 * (91.03 * 15) = 1740\ ft^3$$

Where:
V = Volume of vessel (ft^3)
q = Volumetric flow rate (ft^3/min)
t_r = Residence time (min)

This volume was then divided by two, assuming that there would be two extractors running in parallel, resulting in two vessels requiring a volume of 870 ft^3 each for the example above. With this known volume, the dimensions of the vessels were solved by the following equations. The diameter and height of a cylindrical vessel can be calculated with the vessel volume and an arbitrary height to diameter ratio. This calculations requires to combine two equations. A height to diameter ratio of 3 was used to calculate the dimensions of the solvent extractors and pitching reactors.

$$H_R = \sqrt[3]{\frac{V_R * {R_{\frac{H}{D}}}^2 * 4}{\pi}}$$

$$D_R = \sqrt[3]{\frac{V_R * 4}{\pi * R_{H/D}}}$$

$$H_R = \sqrt[3]{\frac{870 * 3^2 * 4}{\pi}} = 21\ ft$$

$$D_R = \sqrt[3]{\frac{870 * 4}{\pi * 3}} = 7\ ft$$

Where:
H_R = Reactor height (ft)
D_R = Reactor diameter (ft)
V_R = Residence volume (ft^3)
$R_{H/D}$ = Reactor height to diameter ratio

D.12. Power Calculation for Solvent Extractor

The rule of thumb that for moderate to vigorous agitation an impeller should draw 0.5 kW/m^3 power was used to calculate the power for mixers and agitators. This rule of thumb was found in Ulrich [47].

$$P = 0.5 * V * \left(\frac{1m^3}{35.31ft^3}\right) * \left(\frac{1000\ W}{1\ kW}\right) * \left(\frac{1.341E^{-3}hp}{1\ W}\right)$$

$$P = 0.5 * 870 * \left(\frac{1m^3}{35.31ft^3}\right) * \left(\frac{1000\ W}{1\ kW}\right) * \left(\frac{1.341E^{-3}hp}{1\ W}\right) = 16.5\ hp$$

Where:
P = Power (hp)
V = Volume of vessel (ft^3)

D.13. Discounted Cash Flow Rate of Return

The discounted cash flow rate of return (DCFROR) was found using the Ulrich method [51].

$$NPV = 0 = \sum \frac{B}{(1+r)^n}$$

Where:
NPV = Net Present Value
n = Year
B = Profit from year n ($)
r = DCFROR (%)

D.14. Cost Adjustment to Basis Date

The cost adjustment was performed following the procedure presented in Ulrich and using the CPI values found in the Chemical Engineering Magazine [47].

$$FV = PV * \left(\frac{CPI(2016)}{CPI\ (2004)}\right)$$
$$FV = \$5{,}000 * (1.34) = \$6{,}700$$

Where:
FV = Future value at 2016
PV = Present value at 2004

D.15. Fatty Acid Price Update from 2009

The prices for C2-C8 fatty acids were based off of Market Study for Chemicals Derived from Crop Oils [31]. These prices were quoted for 2009. To update the values to a 2016/2017, a ratio was used based on current price quotes for acetic and propionic acid. The ratio of the current to 2009 was found to be 0.88. The following equations show how the remaining C4-C8 acid prices were updated.

$$2016\ Price = r * (2009\ Price/lb)$$

$$2016\ Price = 0.88 * \frac{\$1.13}{lb} = \frac{\$1}{lb}$$

Where:
r= Price ratio based off of current acetic and propionic acid prices

D.16. Amount of Natural Gas Needed

The amount of natural gas needed to heat the boiler feed water was determined from the duty required to heat the water. The equation below describes how this was performed.

$$V = \frac{Heating\ Duty}{Heating\ Value}$$

$$V = \frac{120{,}000\ Btu/min}{1096\ Btu/ft^3} = 110\ ft^3/min$$

Where:
V = Volumetric flow rate of natural gas (ft^3/min)
Heating duty = Duty required to heat the boiler feed water (Btu/min)
Heating value = Heating Value of natural gas (Btu/ft^3)

D.17. Power and Duty Calculation for Pitching Reactor

The power required for the pitching reactor was assumed to be comparable to a same size ribbon mixer. These types of mixers consist of a U-shaped horizontal trough with a double helixal ribbon agitator. Typical ribbon mixers use a 15 hp motor for a 50 kg/min flow rate [66]. This value was then upscaled to the required size we needed (100 kg/min). The following calculation can be seen below.

$$Power = \frac{m_p}{m_t} * 15\ hp$$

$$Power = \frac{100\ kg/min}{50\ kg/min} * 15\ hp = 30\ hp$$

Where:
P= Power required (hp)
M_p= Mass flow rate of pitch (kg/min)
M_t= Typical mass flow rate for ribbon mixers (kg/min)

The duty required for the pitching reactor was found from scaling up the duty of the lab scale pitching reactor. The lab scale reactor used 20% of the 310 W duty for the flow rate of 0.5 g/min. This value was then scaled up to the flow rate of 280,000 g/min, which is what flows through the world scale pitching reactor. The following equations shows how this was done.

$$Power = P_S * \left(\frac{M_L}{M_S}\right) * 0.2$$

$$Power = 310\ W * \left(\frac{280{,}000\ g/min}{0.5\ g/min}\right) * 0.2 = 35{,}000{,}000\ W$$

Where:
P_s= Power required for small scale reactor (W)
M_L= Mass flow rate of large scale (g/min)
M_s= Mass flow rate of small scale (g/min)

D.18. Heat Credit for Extra Syngas Produced

Extra syngas was produced for the base design with carbon fiber recovery. The additional duty not used in the process as a fuel source for the furnaces was then taken as a heat credit. The price of the syngas was found from a known natural gas heating value and price, and was discounted to the syngas' heating value. The below equations describes how this price was found.

$$P_{SG} = P_{NG} * \left(\frac{HD_{SG}}{HD_{NG}}\right)$$

$$P_{SG} = \frac{\$5.60}{1000\ ft^3} * \left(\frac{5856\ \frac{Btu}{lb}}{10920\ \frac{Btu}{lb}}\right) = \frac{\$0.80}{1000\ ft^3}$$

Where:
P_{SG} = Price of syngas ($/1000 ft^3)
P_{NG} = Price of natural gas ($/1000 ft^3)
HD_{SG}= Heating duty of syngas (Btu/lb)
HD_{NG} = Heating duty of natural gas (Btu/lb)

Once the price of the syngas was found, the amount of extra syngas produced was calculated. This was found from the left over heating duty. The below equations describes how this was accomplished.

$$V = \frac{\frac{Leftover\ Duty}{HD_{SG}}}{\rho_{SG}}$$

$$V = \frac{\frac{722{,}900\frac{Btu}{min}}{5856\ \frac{Btu}{lb}}}{3.27\frac{lb}{ft^3}} = 37.8\ \frac{ft^3}{min}$$

Where:
V= Volumetric flow rate of syngas (ft^3/min)
HD_{SG}= Heating duty of syngas (Btu/lb)
ρ_{SG}= Density of syngas (lb/ft^3)

D.19. Mesophase Pitch Crushing Sizing

The pitch crusher was sized with the following equation using a known conveyor length and mass. The unit was designed as a roll crusher, which means a reduction ratio of 4 was used [47].

$$Power = 0.2 * m * R$$

$$Power = 0.2 * 1.6 * 4 = 1.3\ kW$$

Where:
Power = Power required for crusher (kW)
m = Mass flow rate through crusher (kg/s)
R = Reduction ratio (dimensionless)

D.20. Conveyor Sizing

The conveyors used to cool and haul the pitch product were sized using the equation shown below [47].

$$Power = \ m^{0.85} * 0.07 * L$$

$$Power = (1.63\frac{kg}{s})^{0.85} * 0.07 * 6\ m = 0.6\ kW$$

Where:
Power = Power required for conveyor (kW)
m = mass flow rate of pitch (kg/s)
L = Length of conveyor (m)

D.21. Margin between Soybean Oil and Transportation Fuel Calculation

The margin between the transportation fuels produced for each process and the cost of the TAG oil used as the raw material (soybean oil) was calculated on a mass basis. First, the amount of each transporation fuel produced from processing of 1 kg of soybean oil was found from the following equation.

$$X = \frac{m_T}{m_S}$$

$$X = \frac{212\ kg/min}{1000\ kg/min} = 0.212$$

Where:
X = Transportation fuel production for 1 kg/min of inlet soybean oil
m_t= Mass of transportation fuel produced (kg/min)
m_S= Inlet mass flow rate of soybean oil (1000 kg/min)

Once the production of all three transportation fuels were found on a mass basis the margin between the fuel products and raw material could be found. The following equation was used, based on 0.12/kg soybean oil production of naphtha, 0.212/kg soybean oil production of jet fuel, and 0.214/kg soybean oil production of diesel fuel no. 2.

$$Margin = \Big((X_N * P_N) + \big(X_J * P_J\big) + (X_D * P_D)\Big) - (X_S * P_S)$$

$$Margin = \left(\left(0.127 * \frac{\$0.56}{kg}\right) + \left(0.212 * \frac{\$0.485}{kg}\right) + \left(0.214 * \frac{\$0.486}{kg}\right)\right)$$

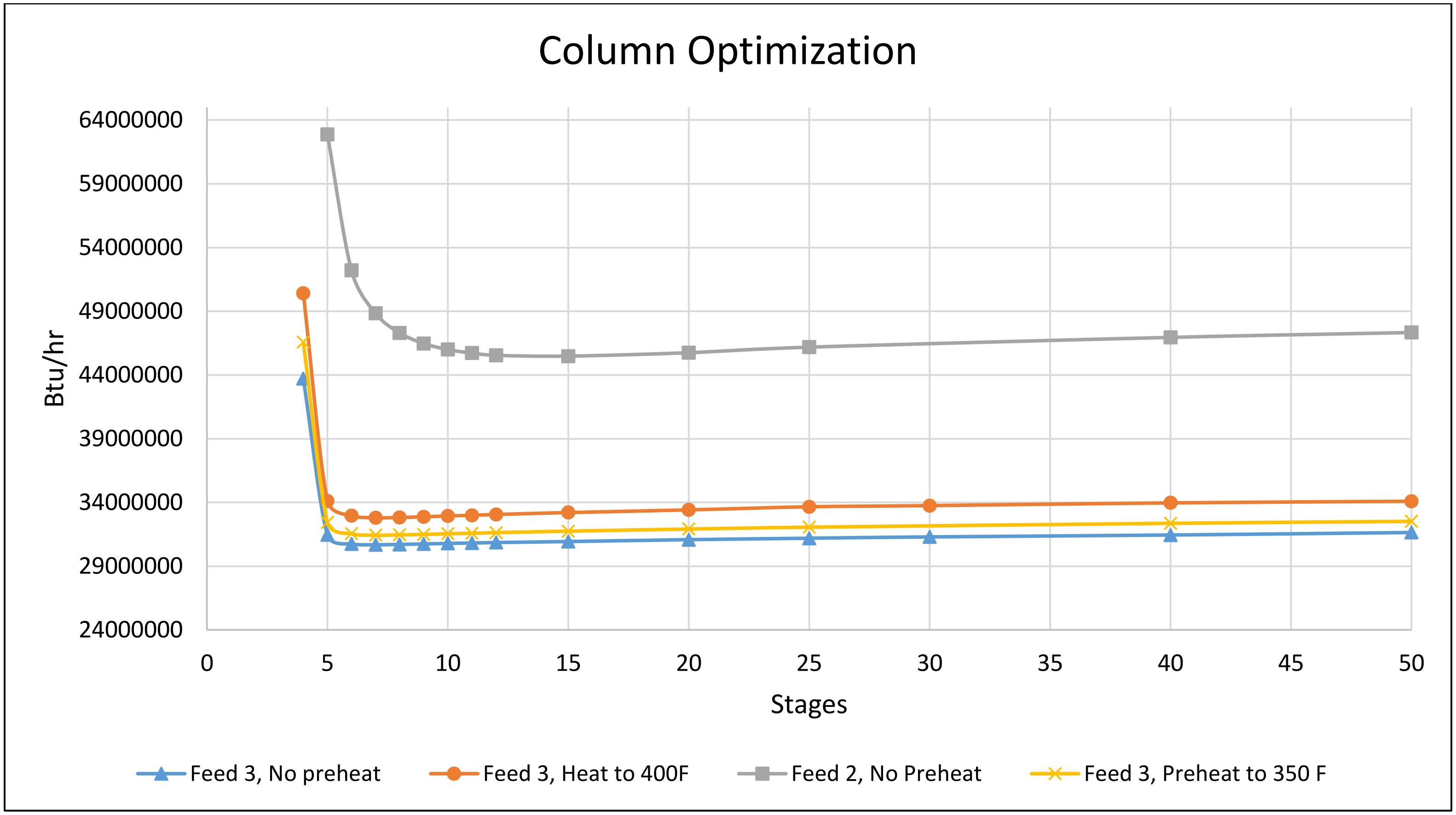
$$- \left(1 * \frac{\$0.60}{kg}\right) = -0.324$$

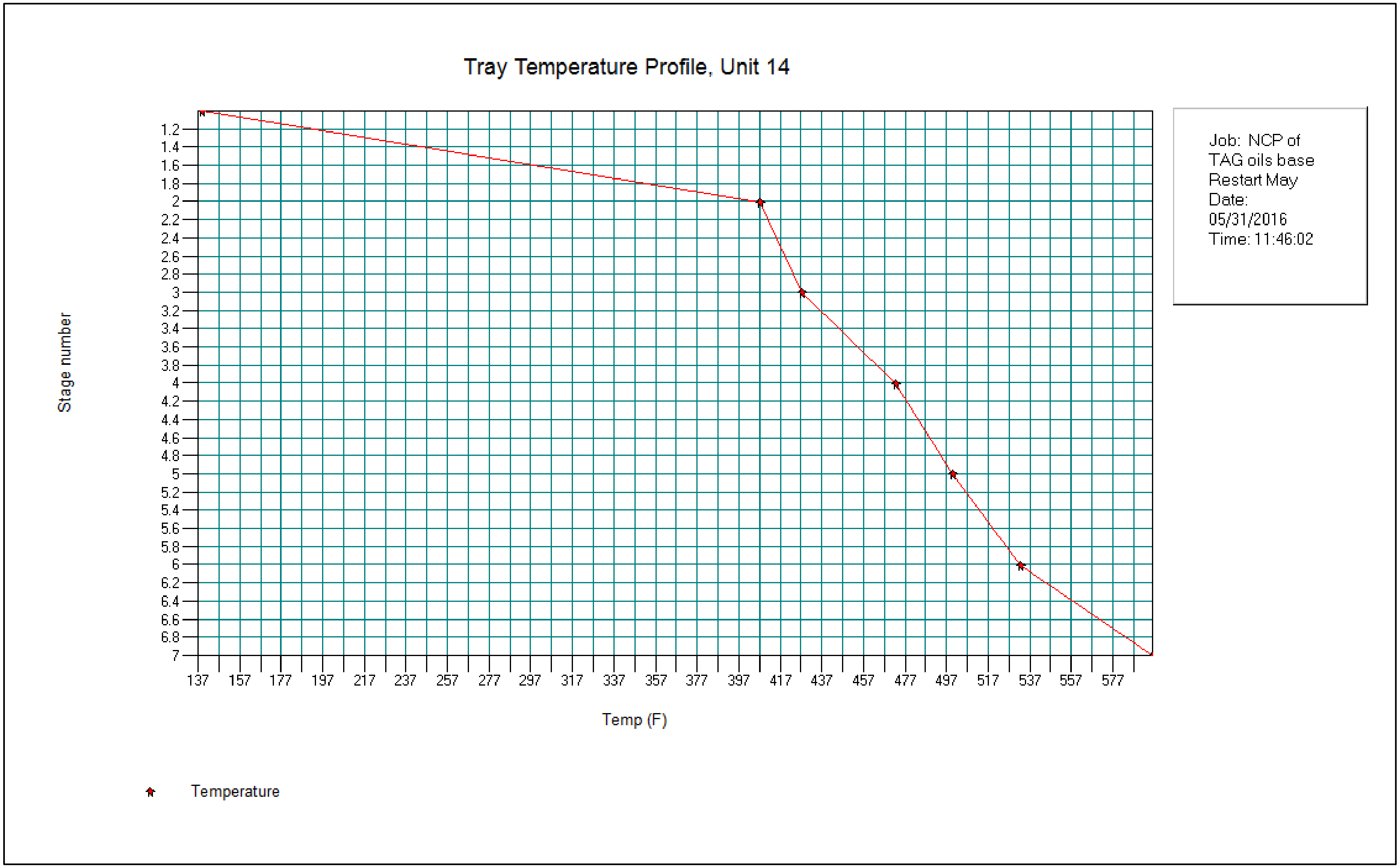
Where:
X_N= Naphtha production per kg of soybean oil
X_J= Jet fuel production per kg of soybean oil
X_D= Diesel fuel production per kg of soybean oil
X_S=1 kg of soybean oil
P_N=Price of naphtha ($/kg)
P_J=Price of jet fuel ($/kg)
P_D=Price of diesel fuel ($/kg)
P_S=Price of soybean oil ($/kg)

Appendix E. Distillation Column Optimization

E.1. Base Design Column Optimization

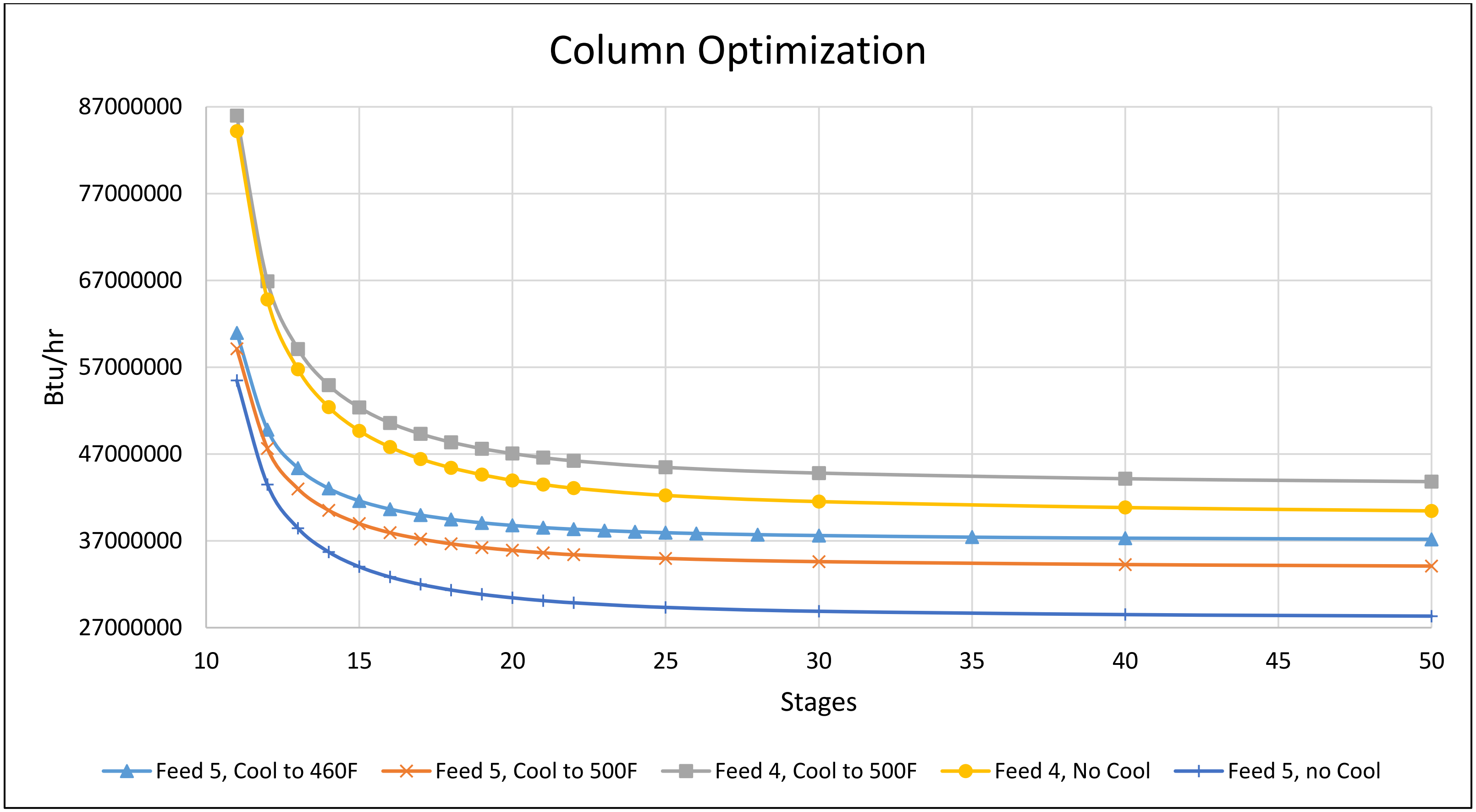
Atmospheric Column (D-201)

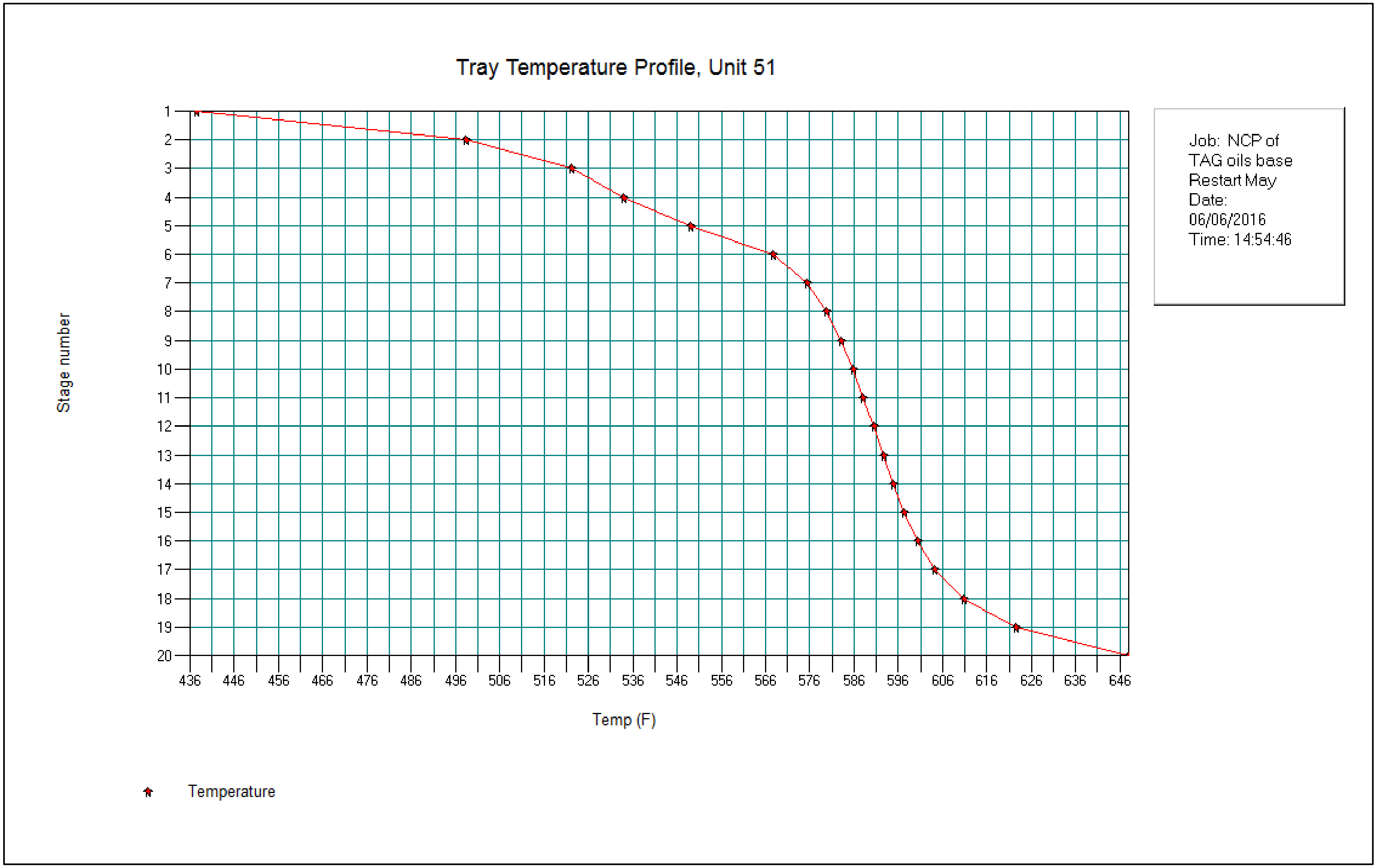




Column temperature profile.

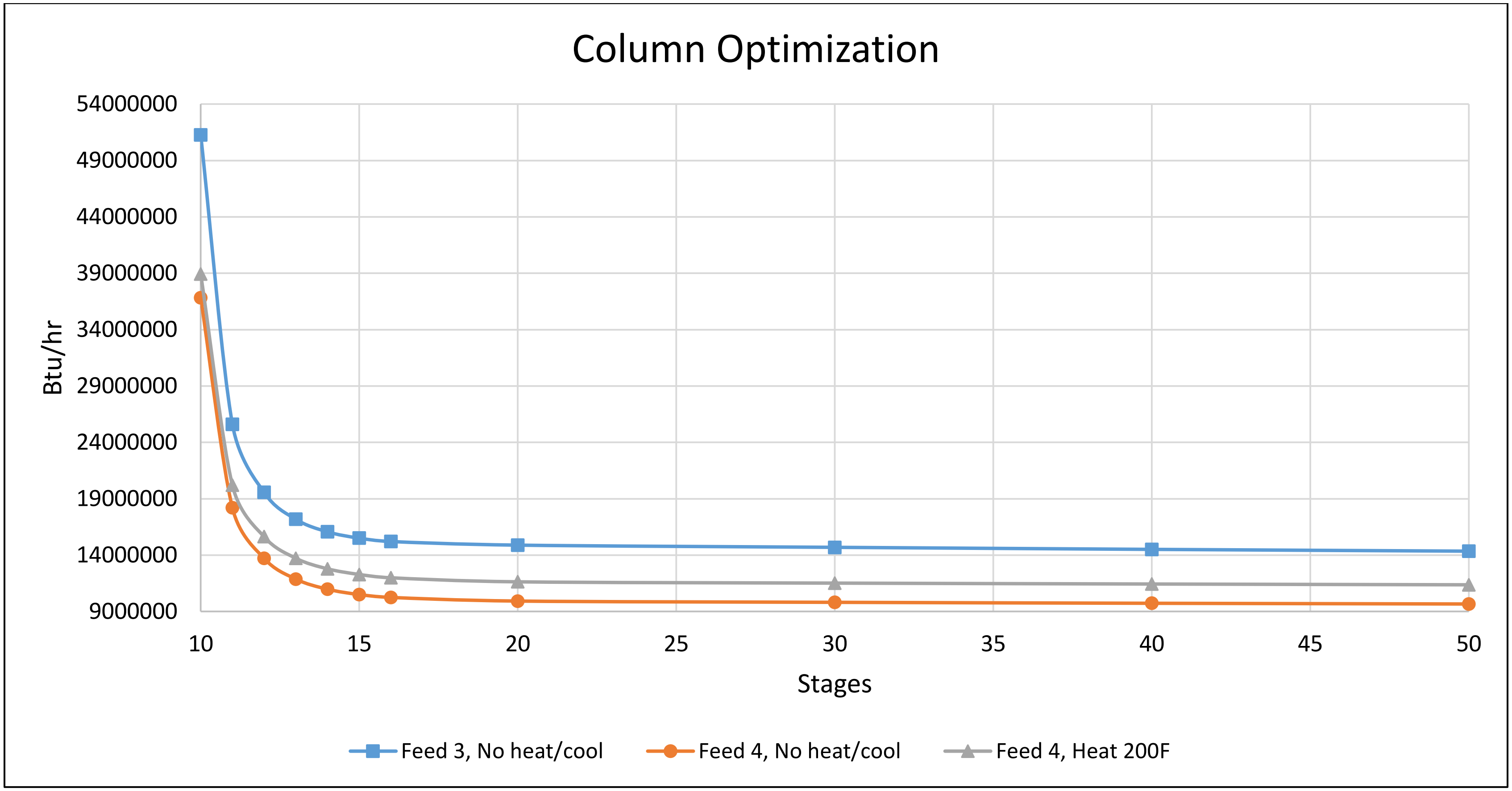
Vacuum Column (D-202)

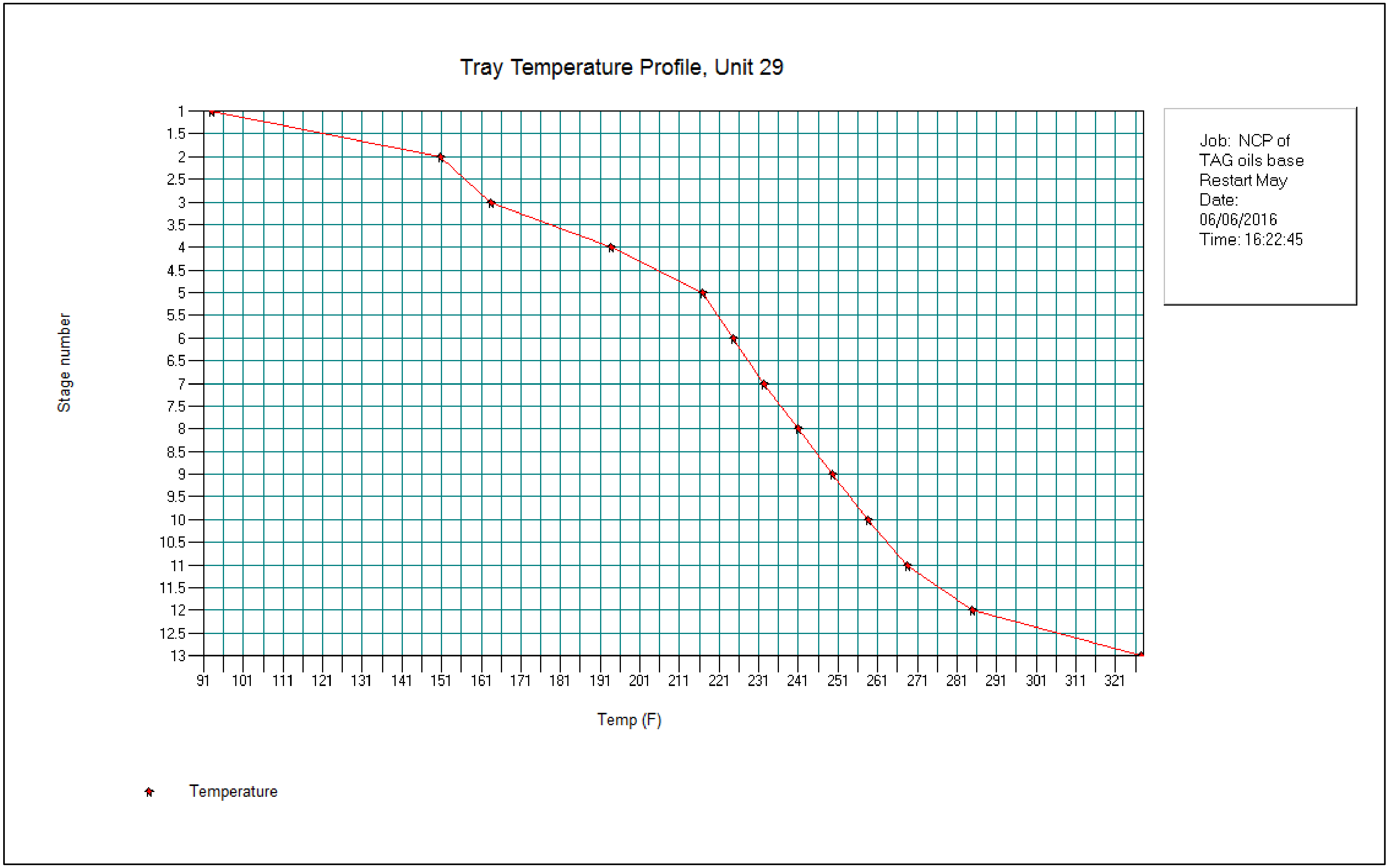




Column temperature profile.

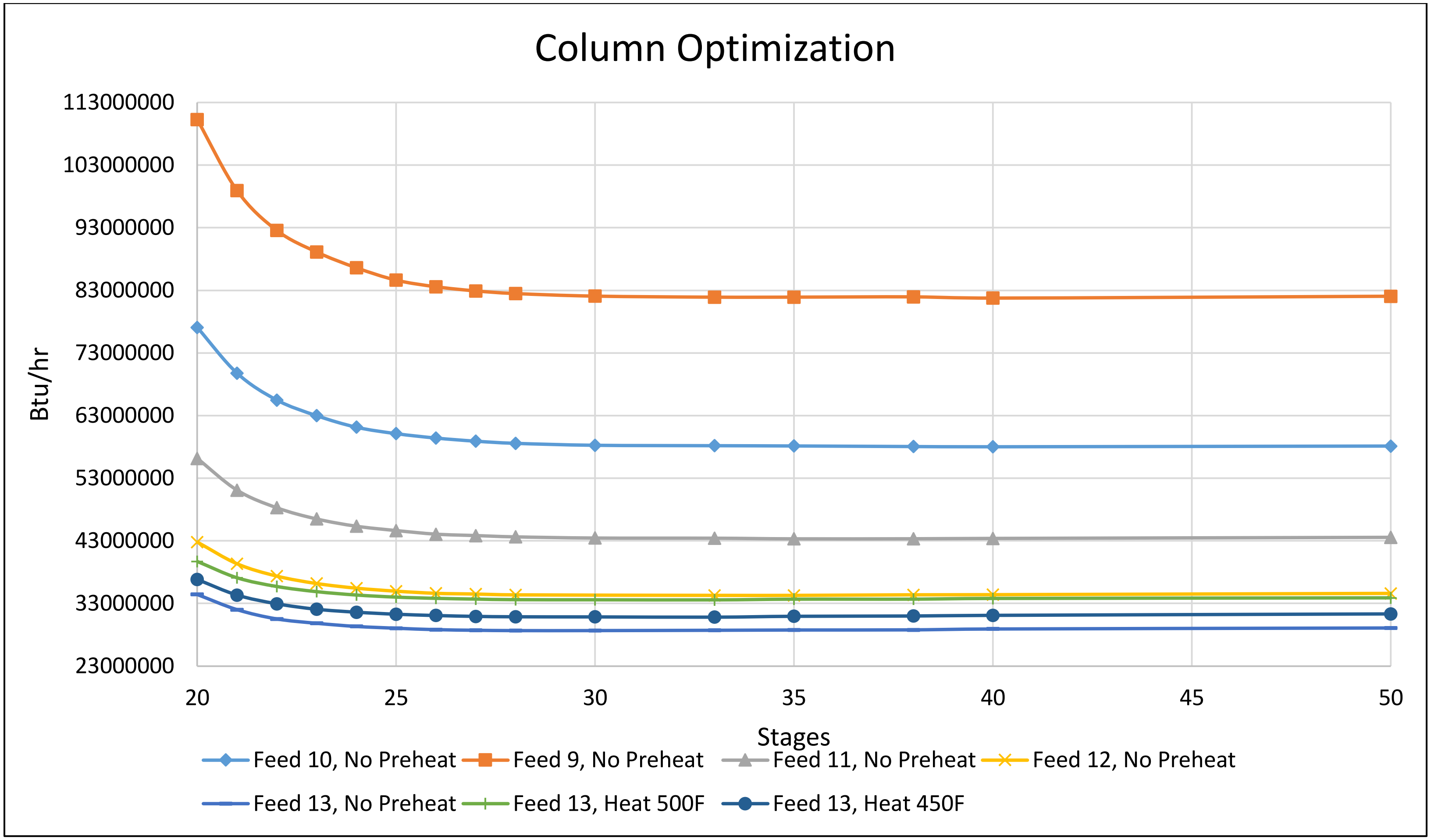
Hexane Splitter (D-203)

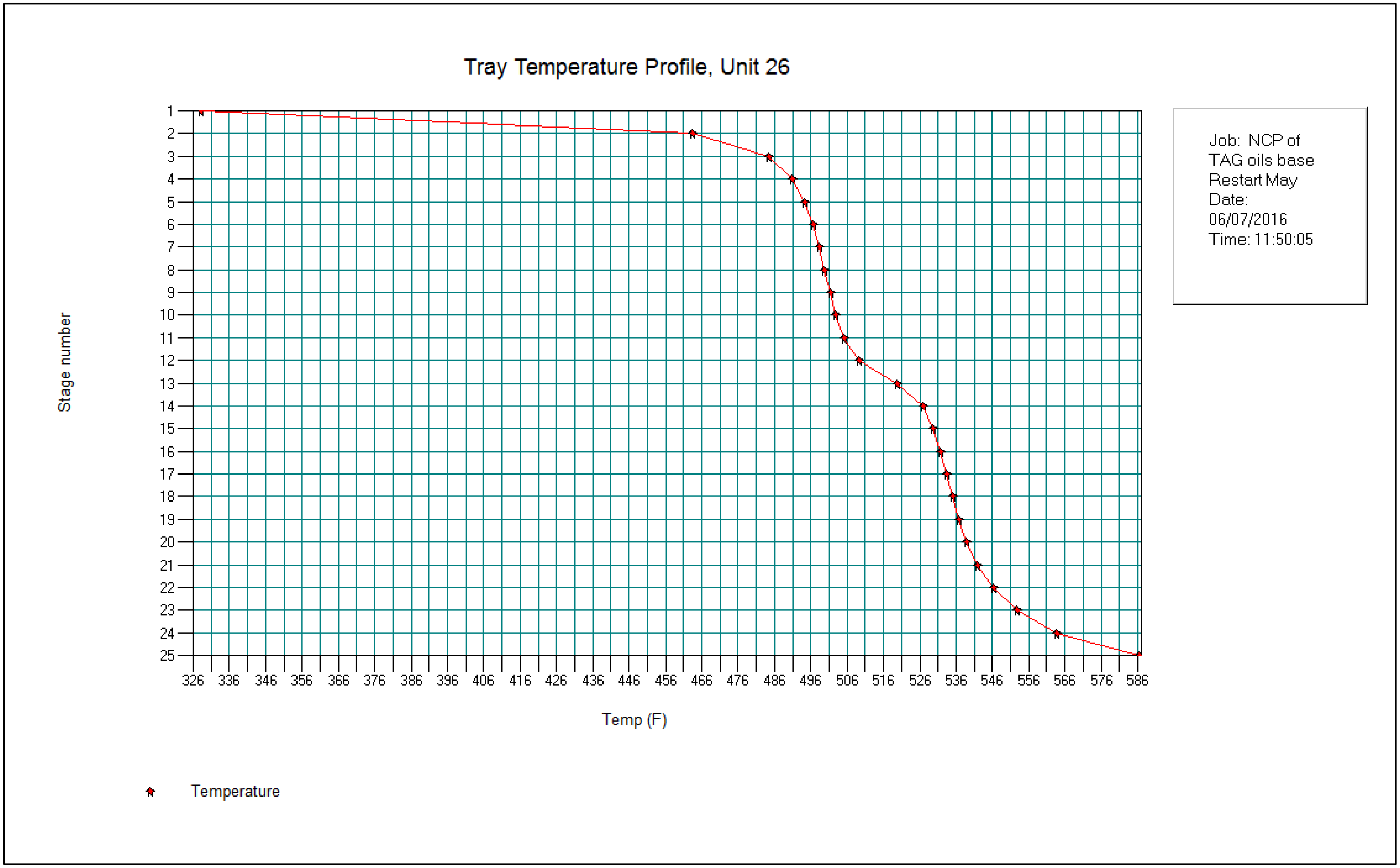




Column temperature profile.

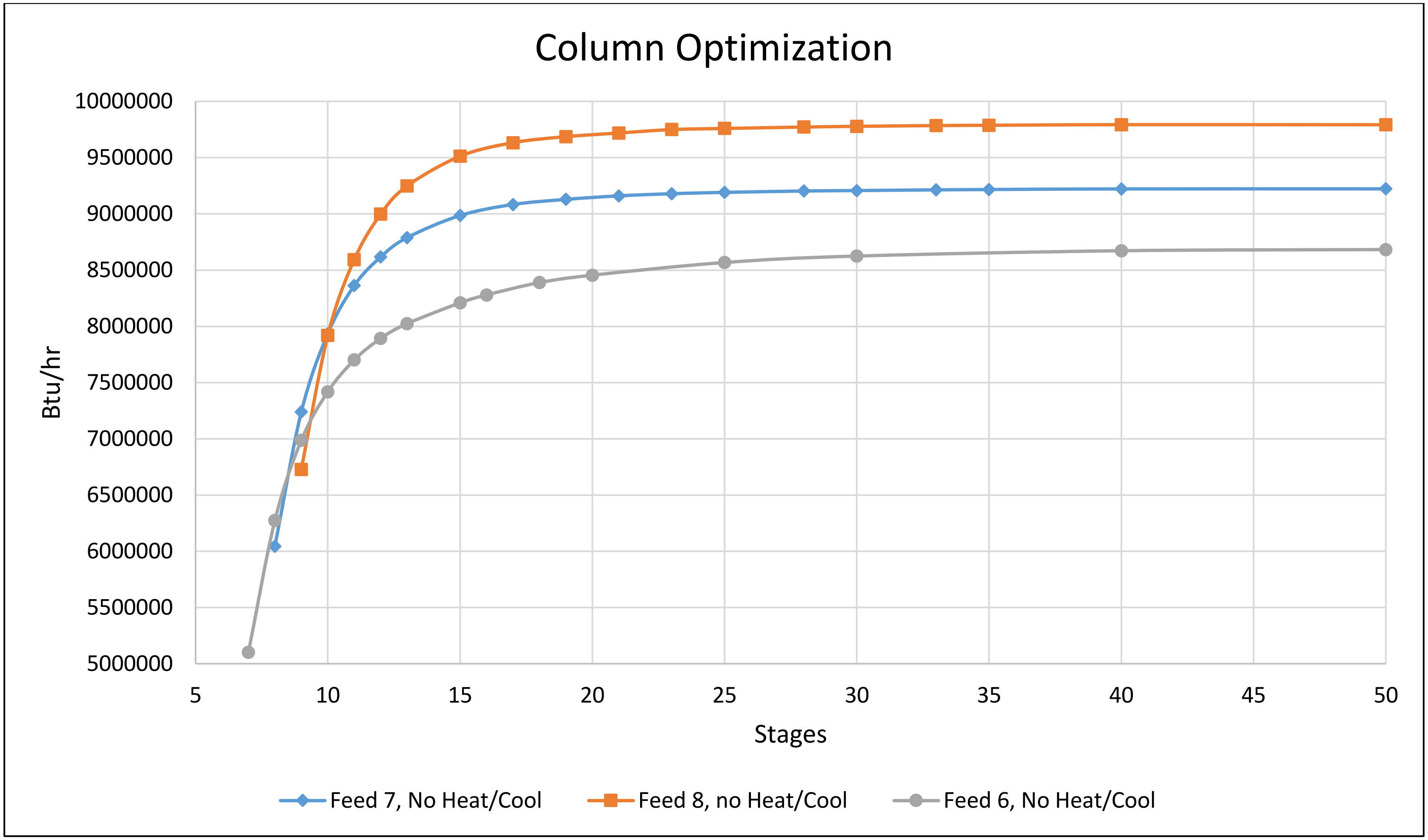
Jet-Diesel Cut Column (D-204)

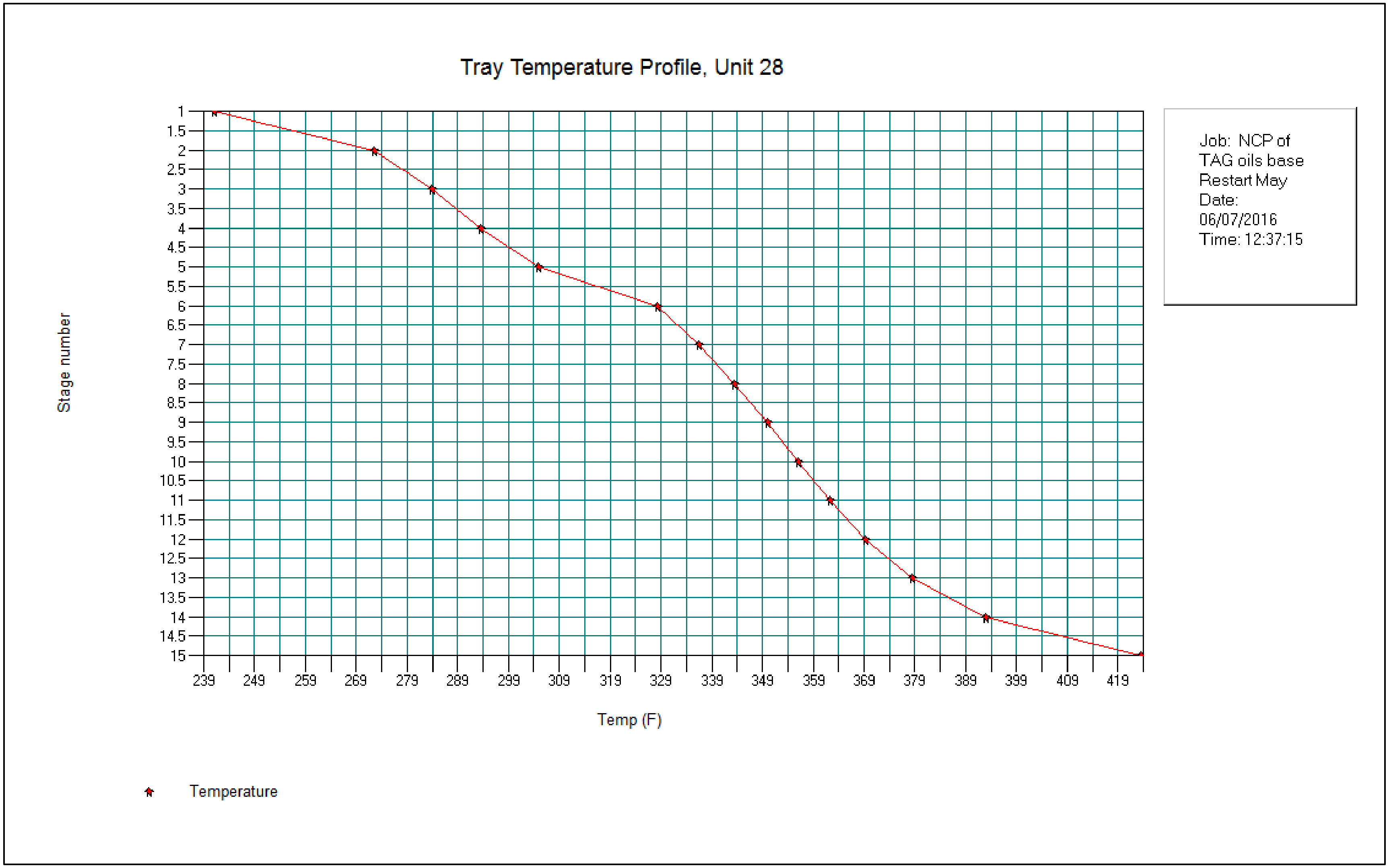




Column temperature profile.

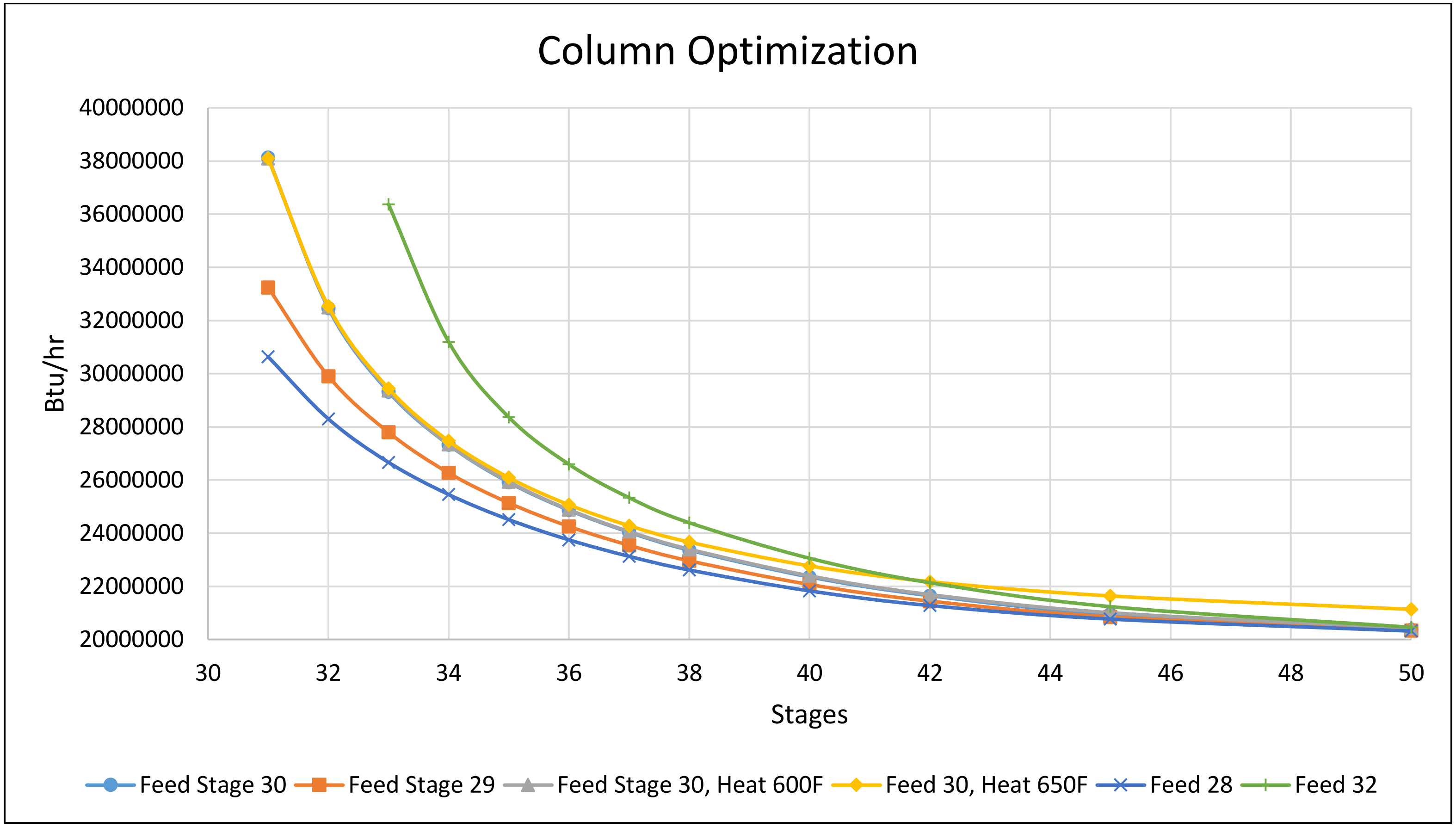
Naphtha Jet Cut Column (D-205)

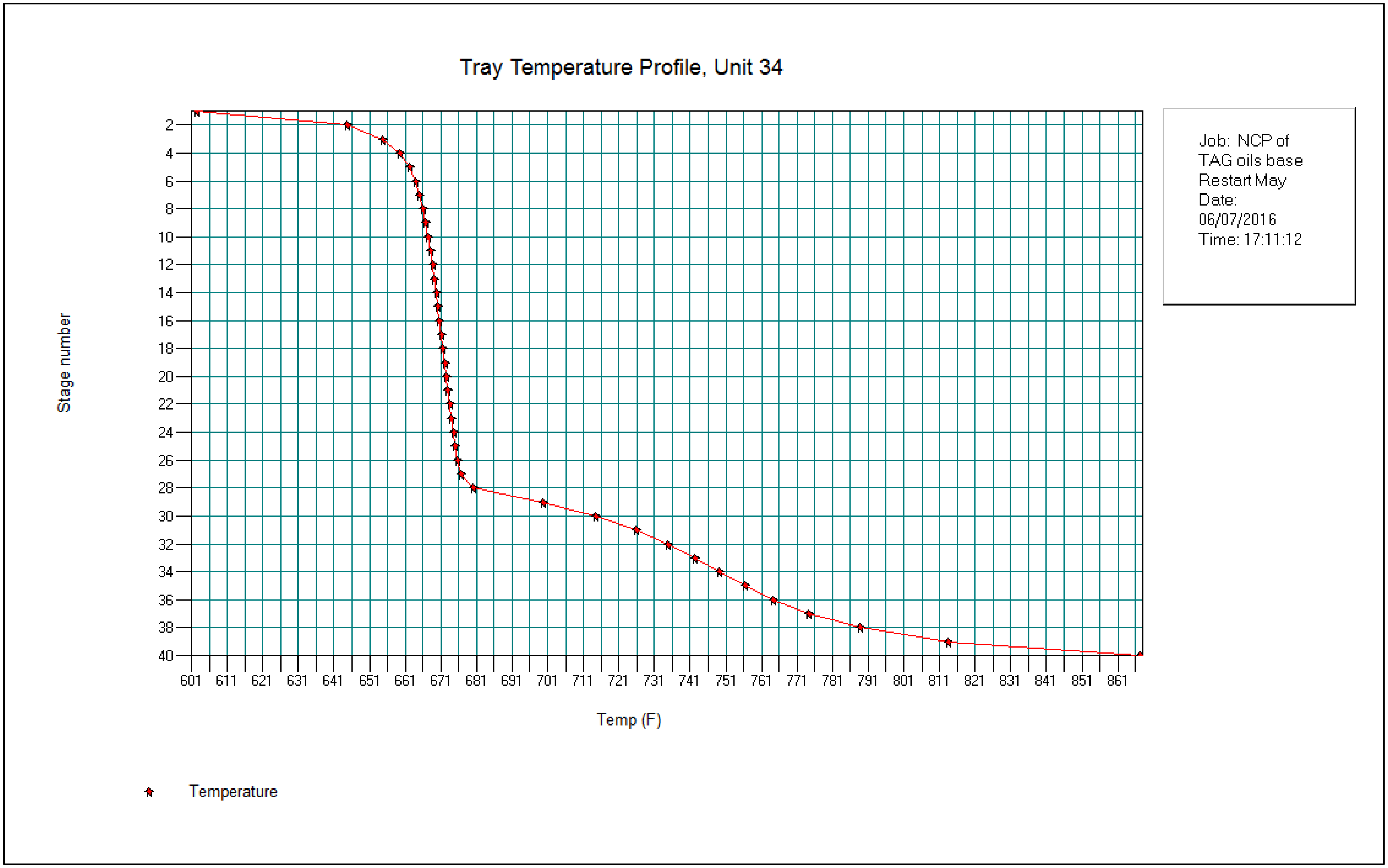




Column temperature profile.

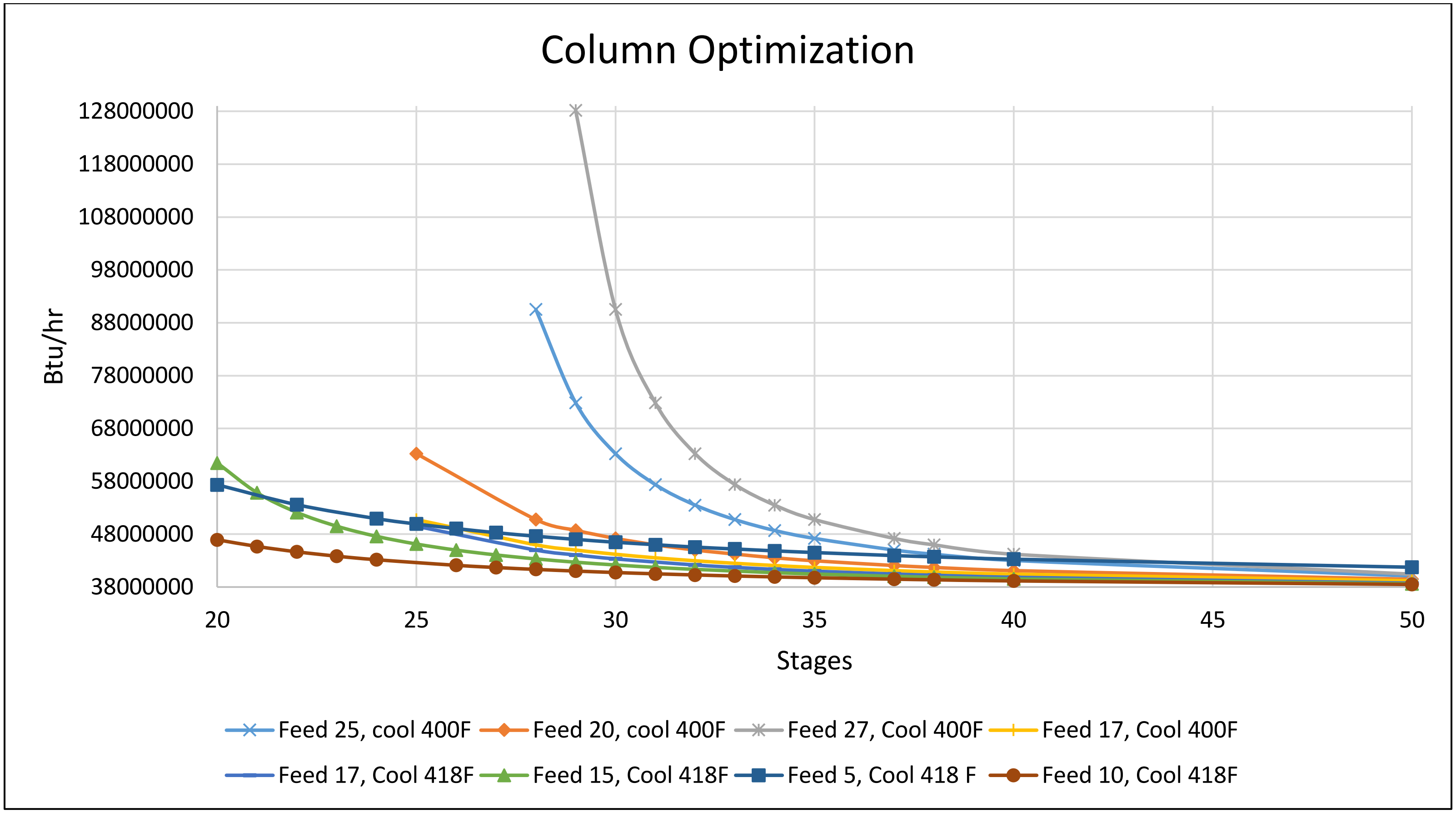
Diesel-Fuel Oil Cut Column (D-206)

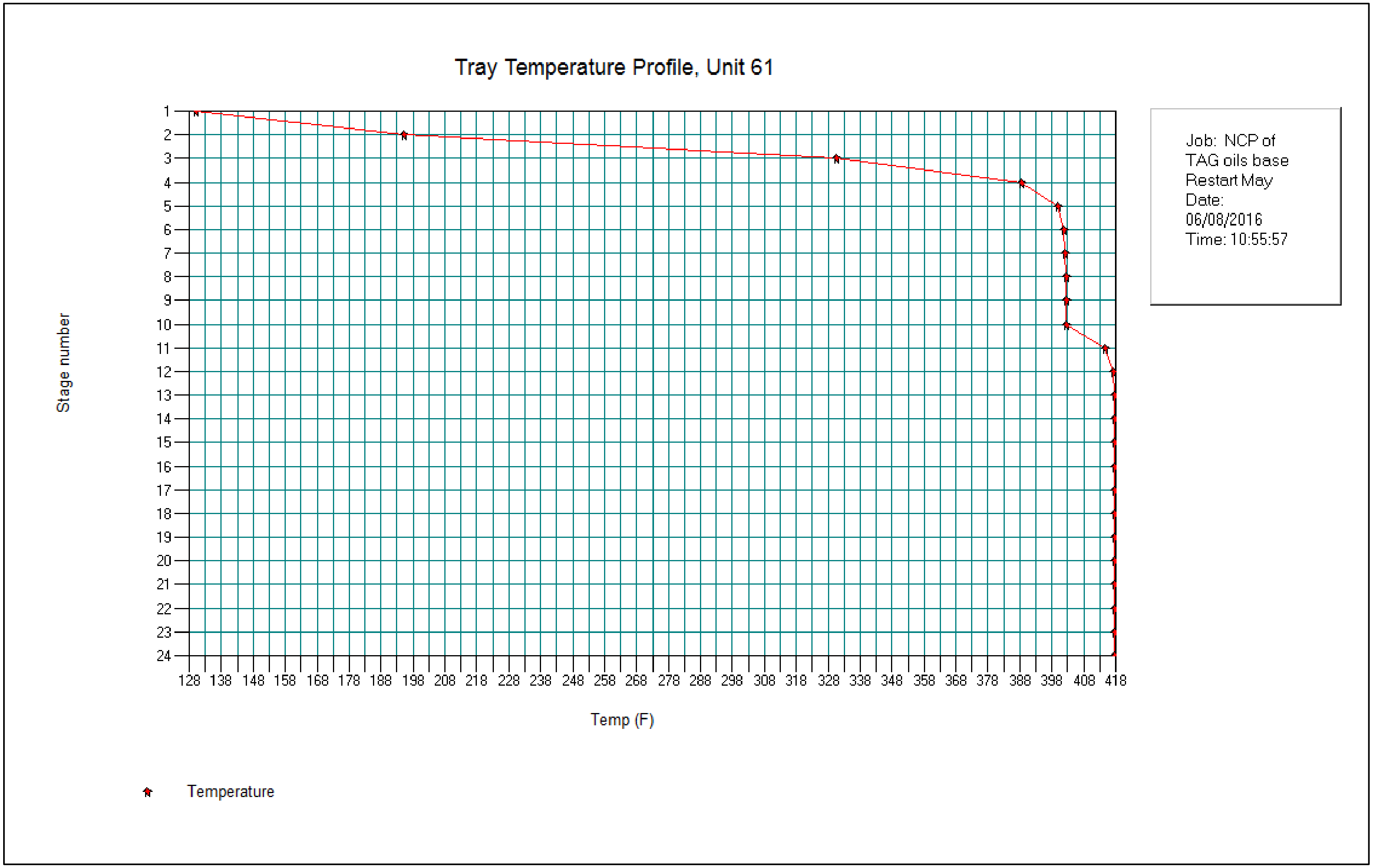




Column temperature profile.

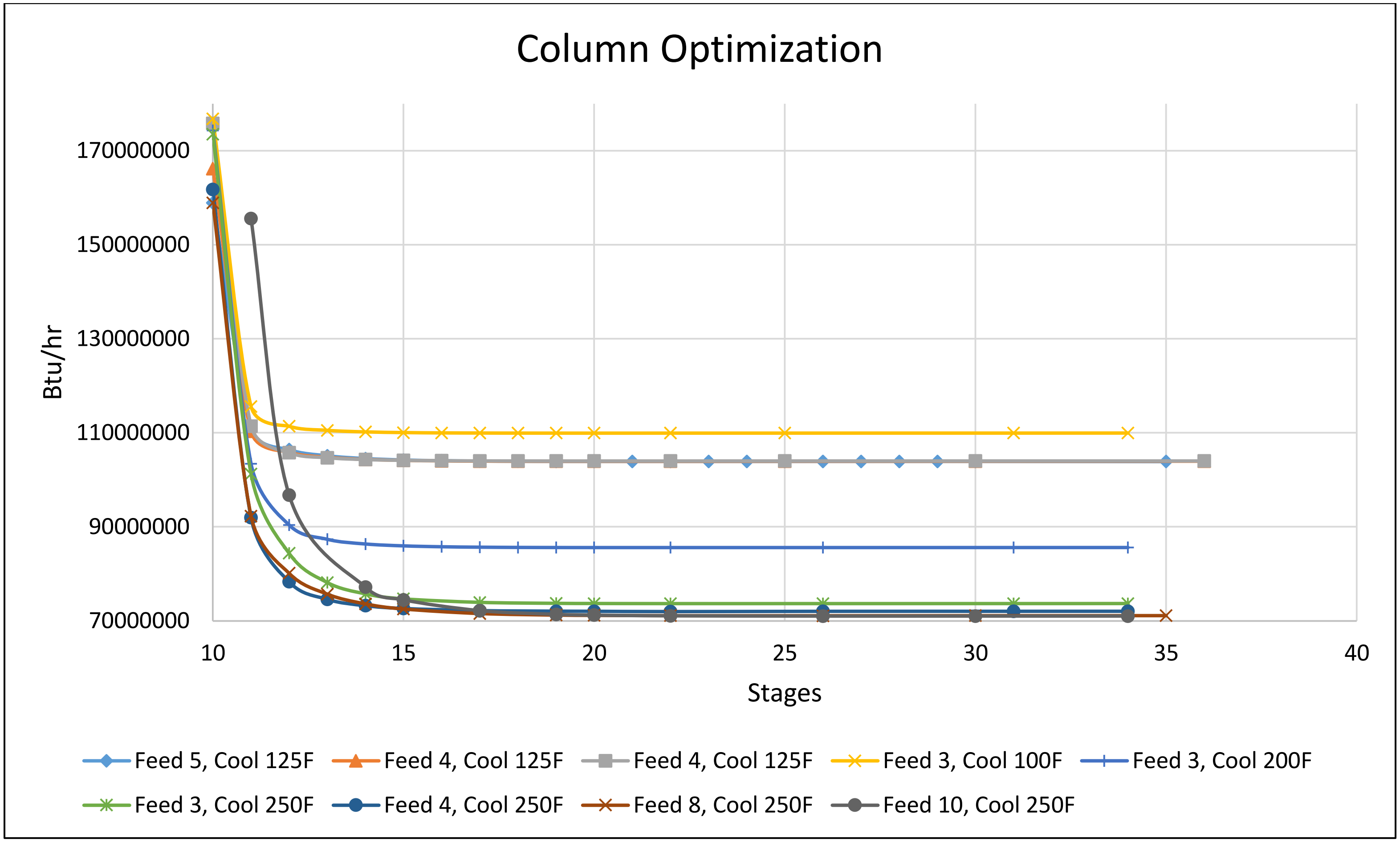
Varsol Recovery Column (Removed)

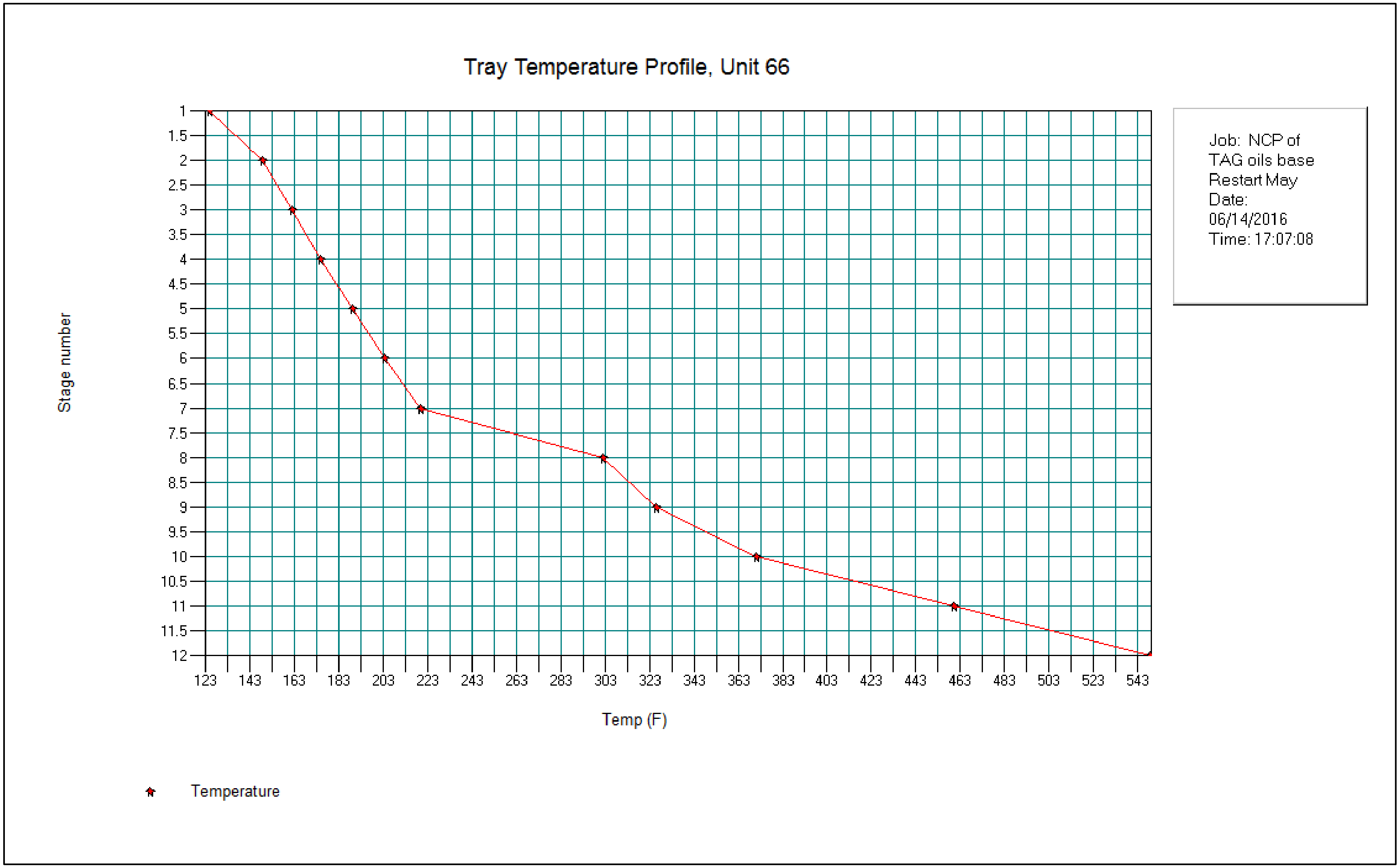




Column temperature profile.

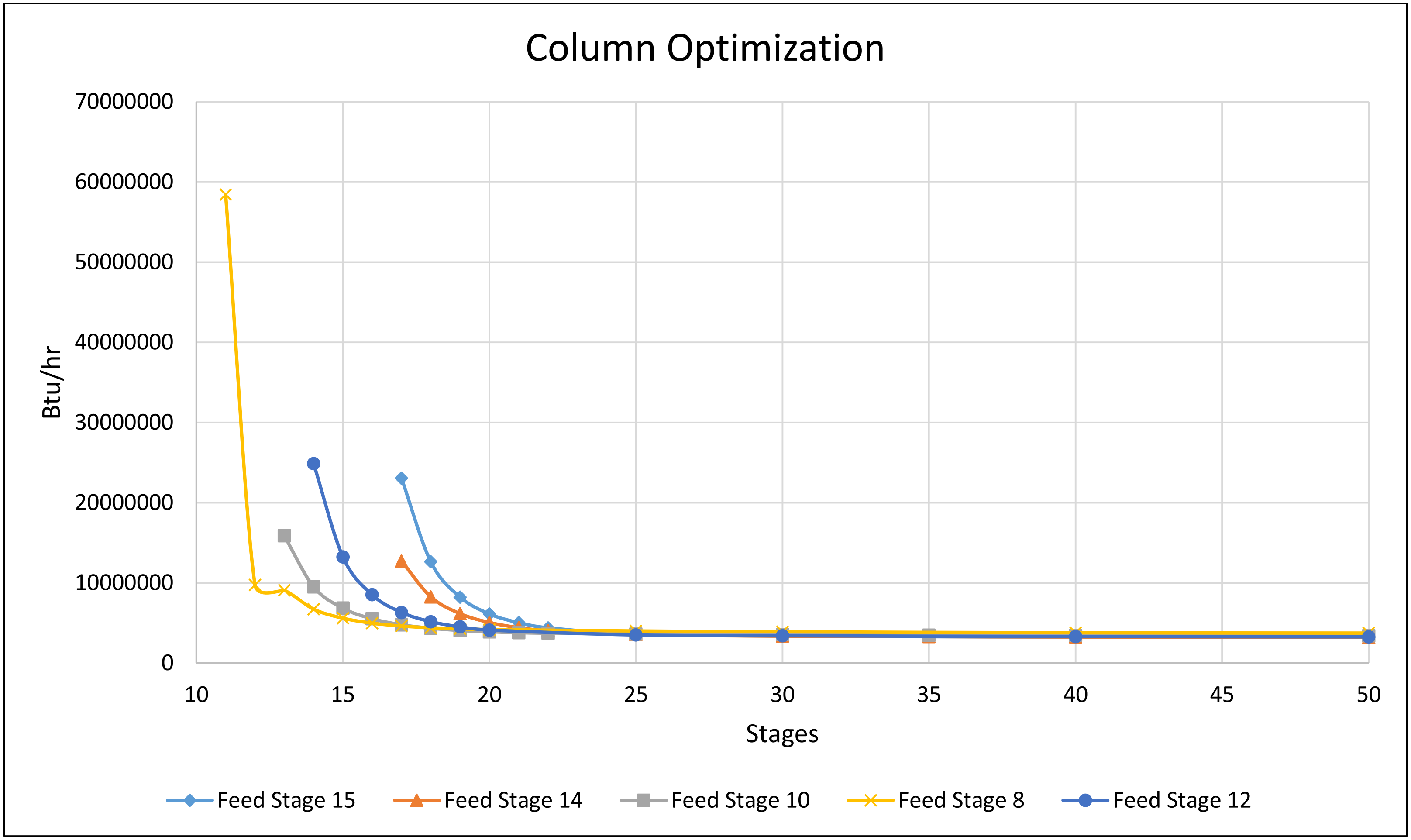
Debutanizer Column (D-210)

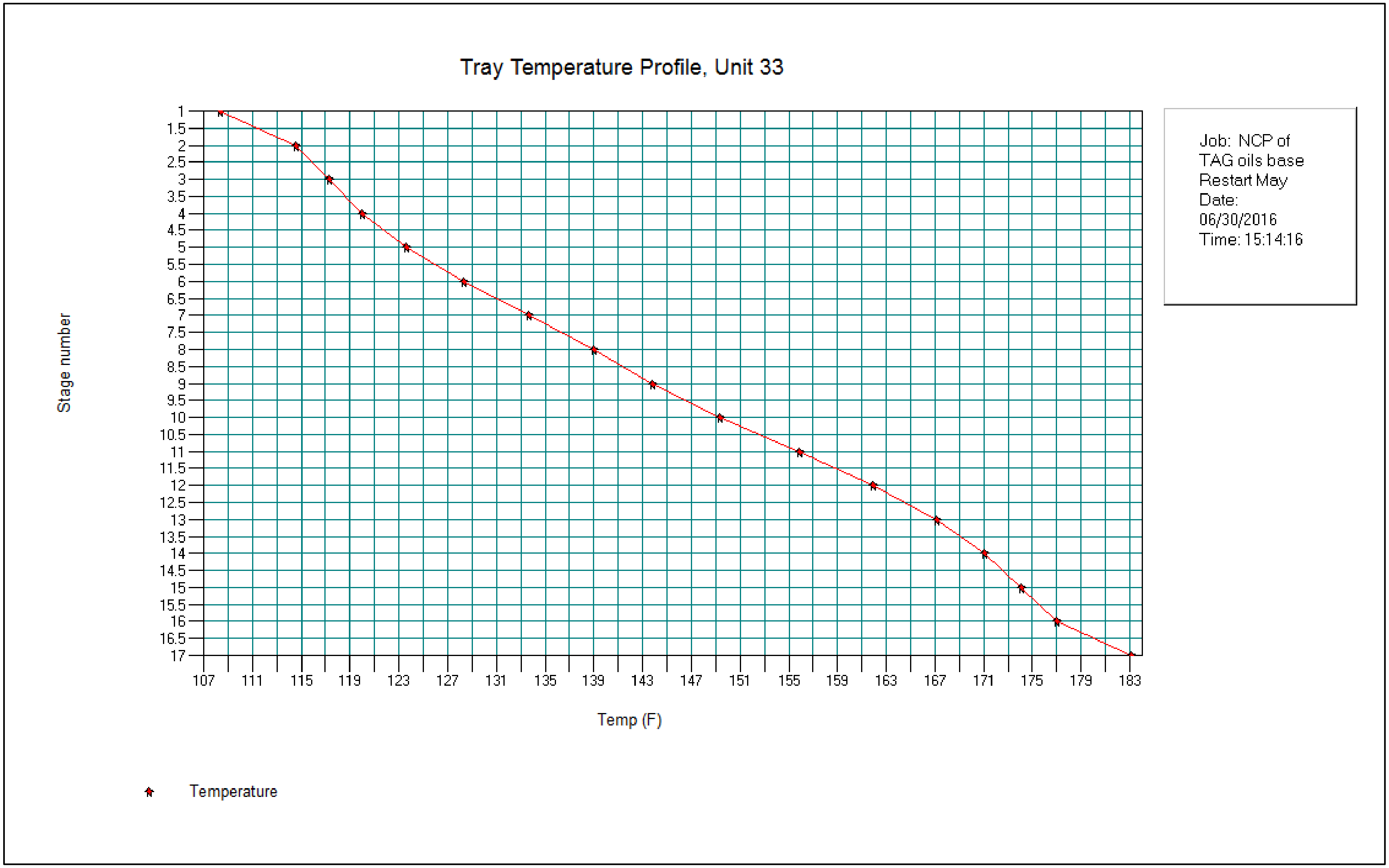




Column temperature profile.

C5 Product Column (D-211)

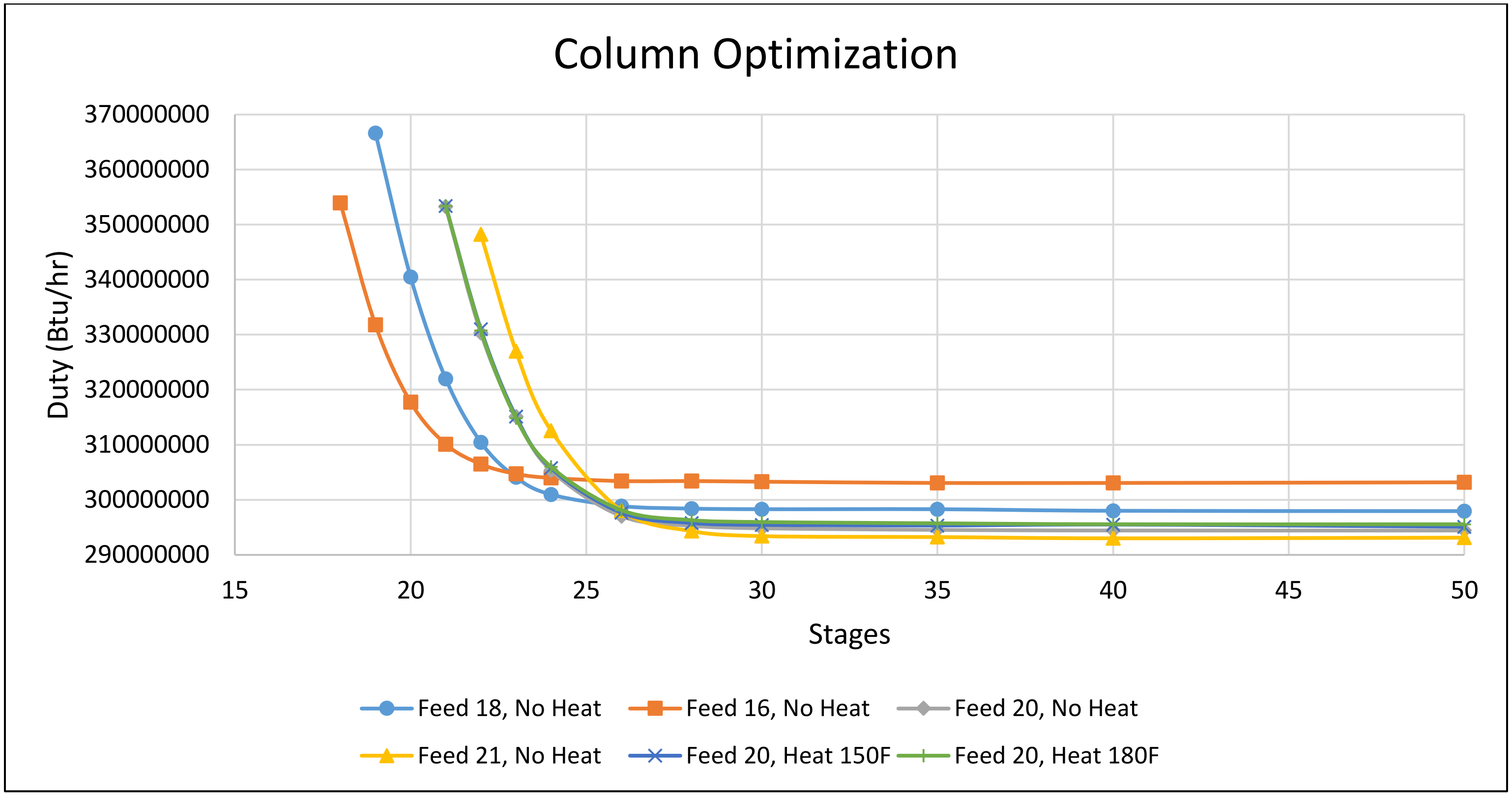




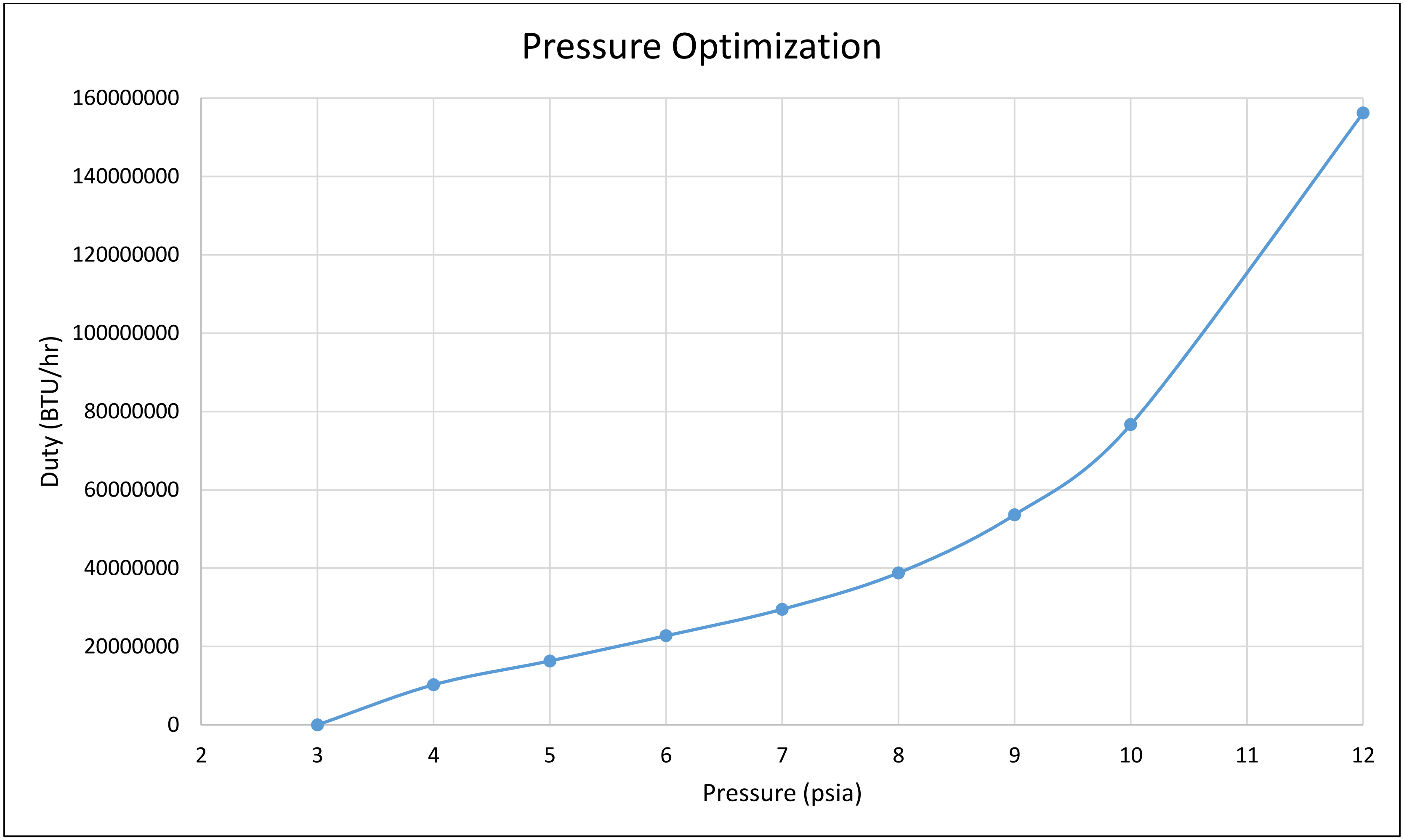
Column temperature profile.

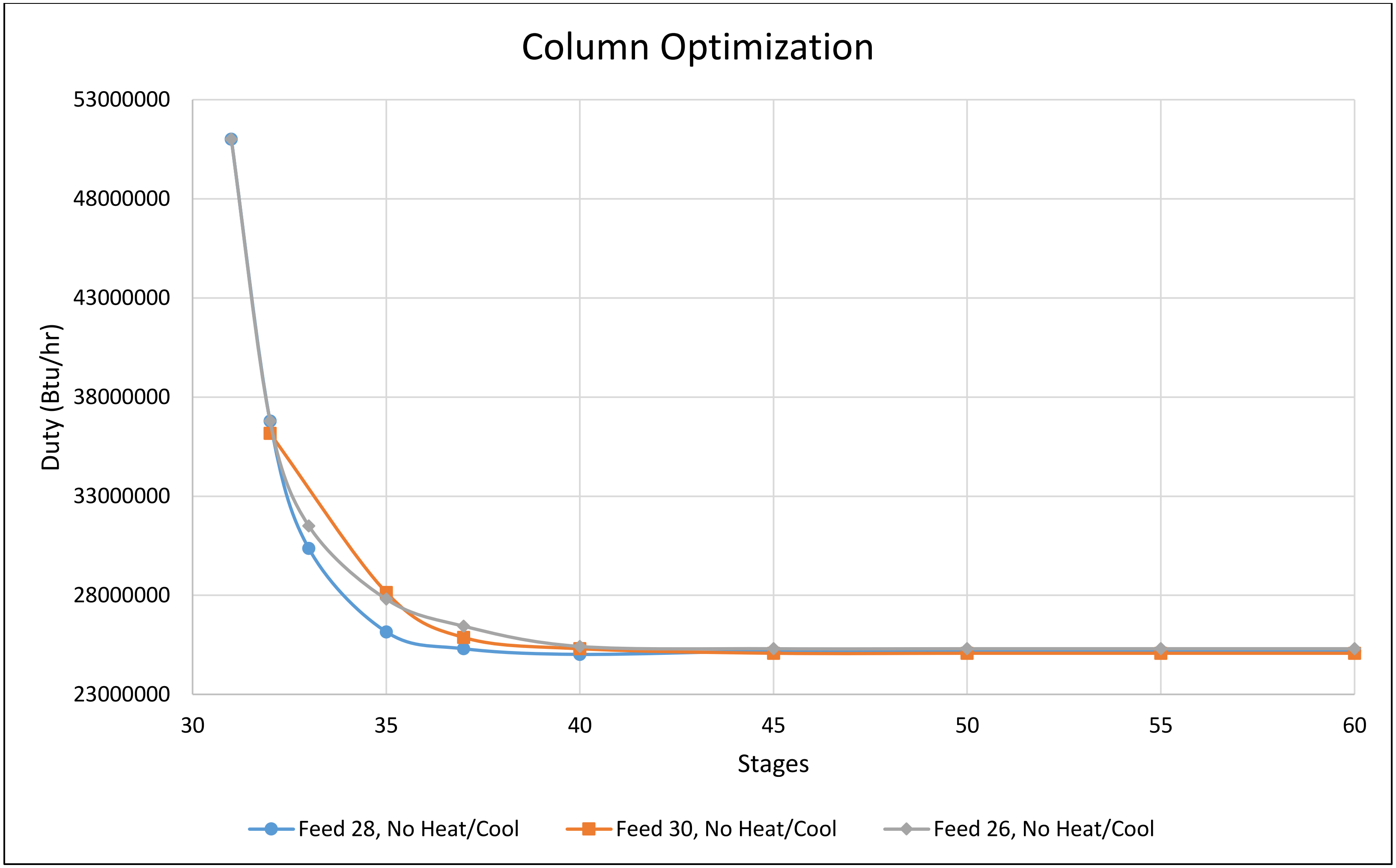
E.2. Fatty Acid Recovery Design

Water Removal Column (D-703)



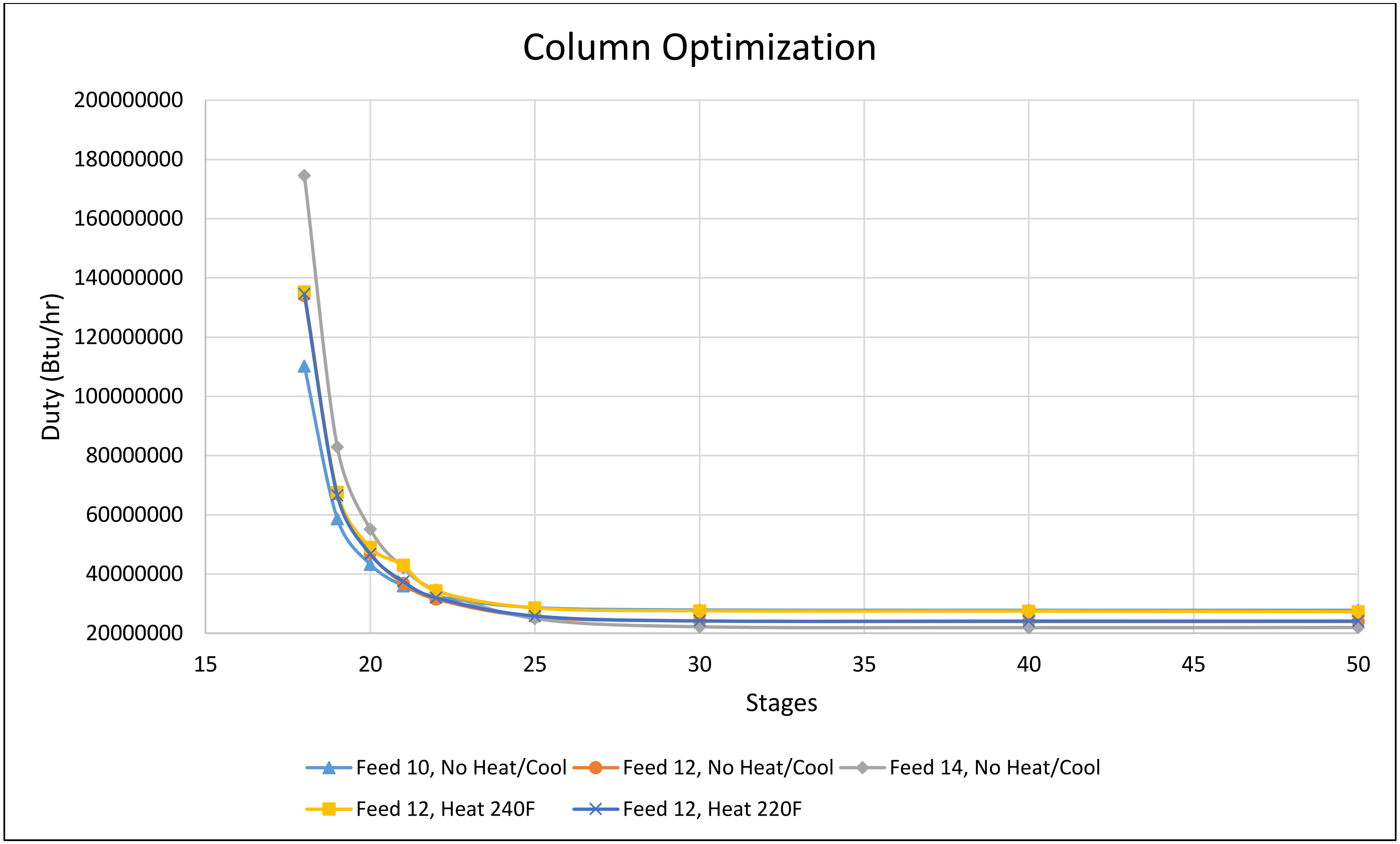
C3 Acid Separator (D-704)

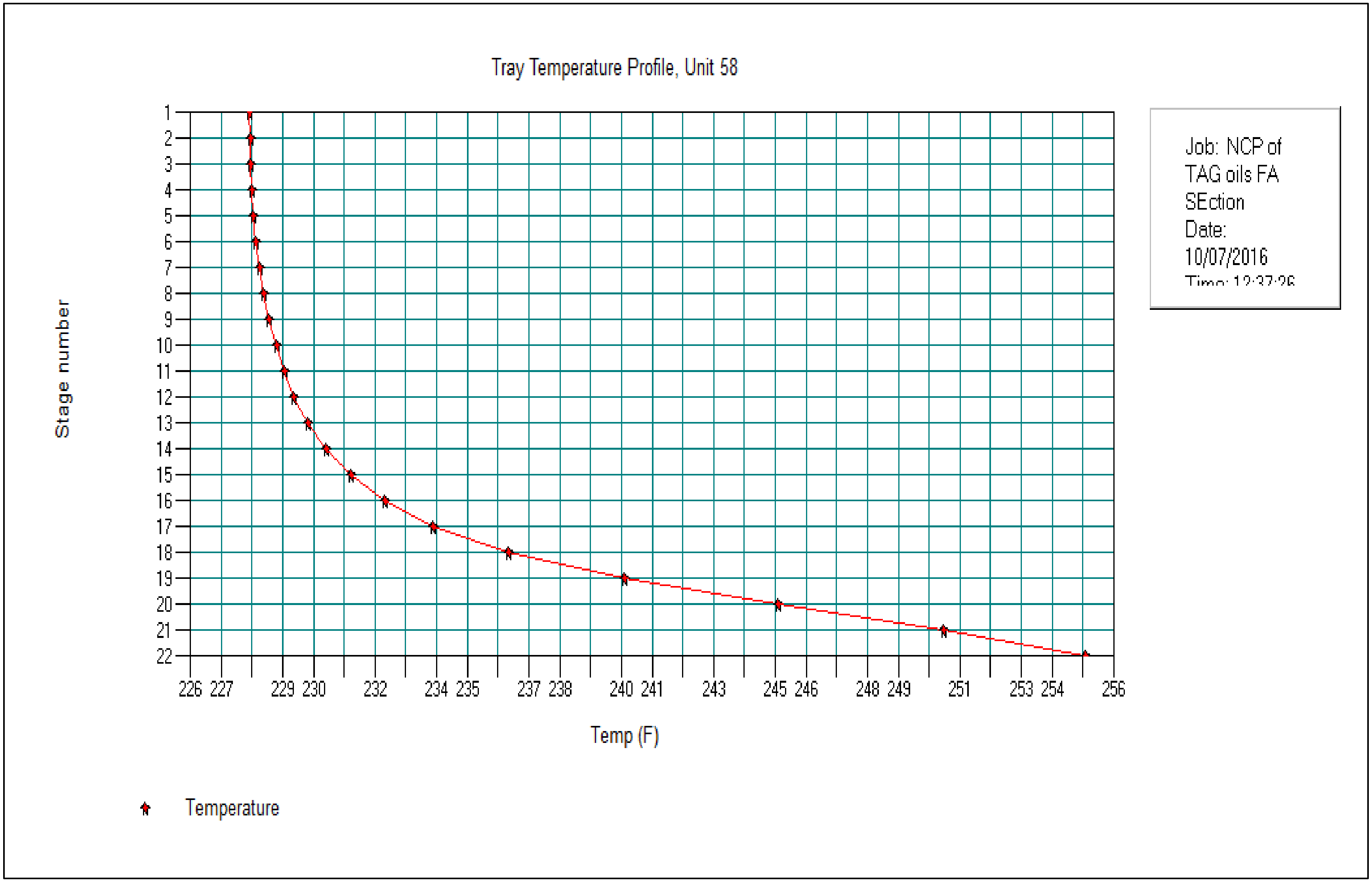




Column Optimization
53000000
48000000
43000000
38000000
33000000
28000000
23000000
Duty (Btu/hr)
30
35
40
45
50
55
60
Stages
Feed 28, No Heat/Cool
Feed 30, No Heat/Cool
Feed 26, No Heat/Cool

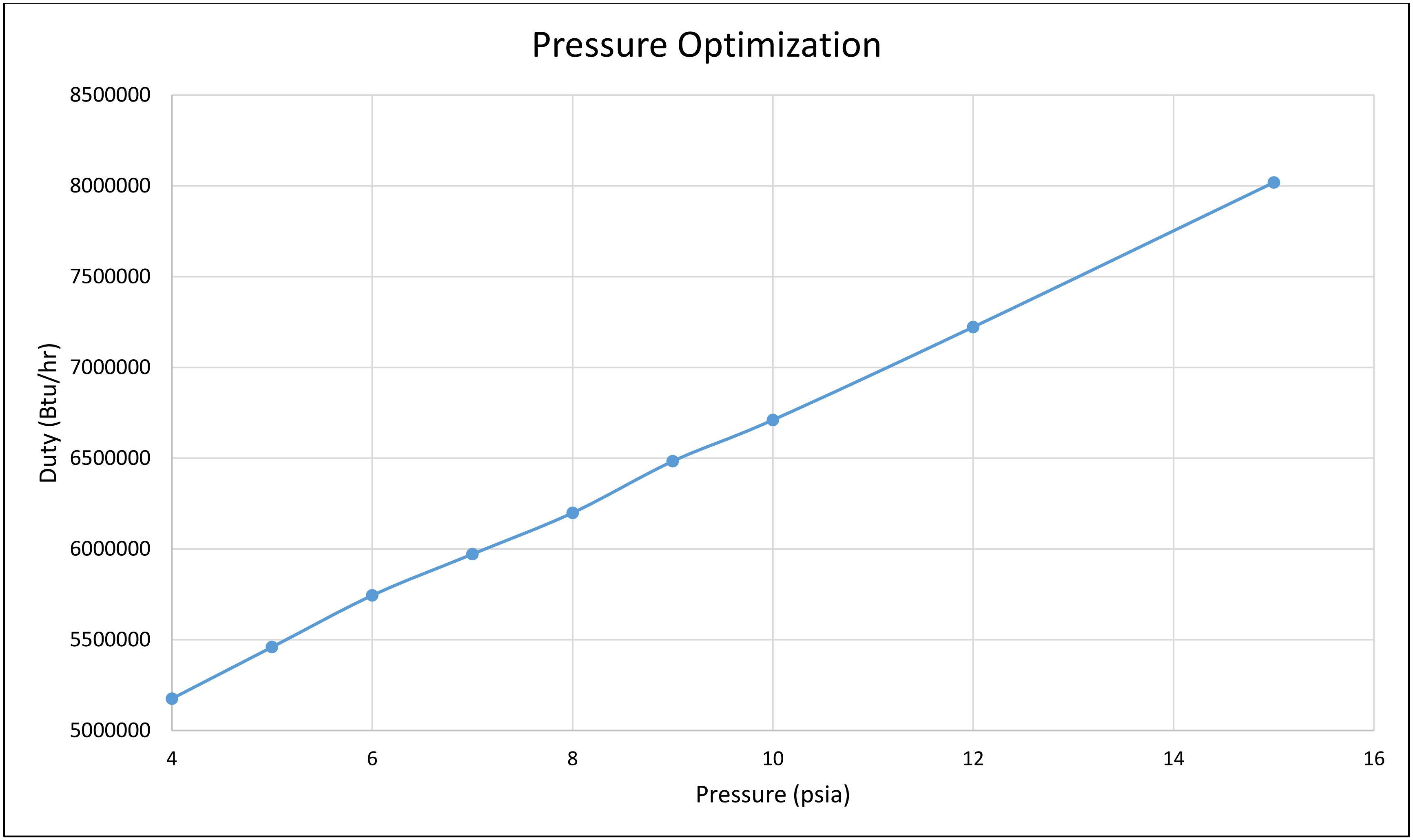
Acetic Acid Column (D-705)

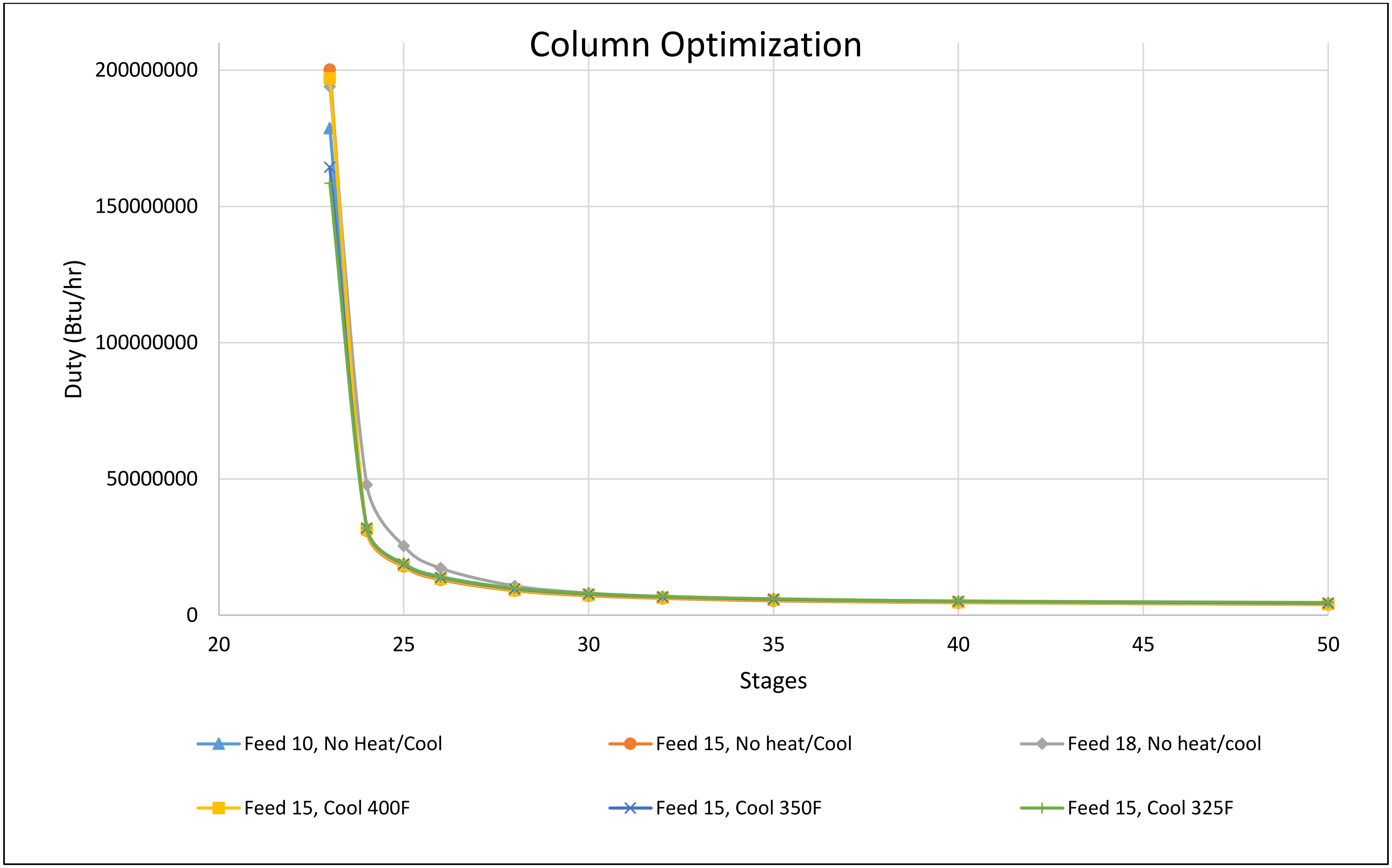




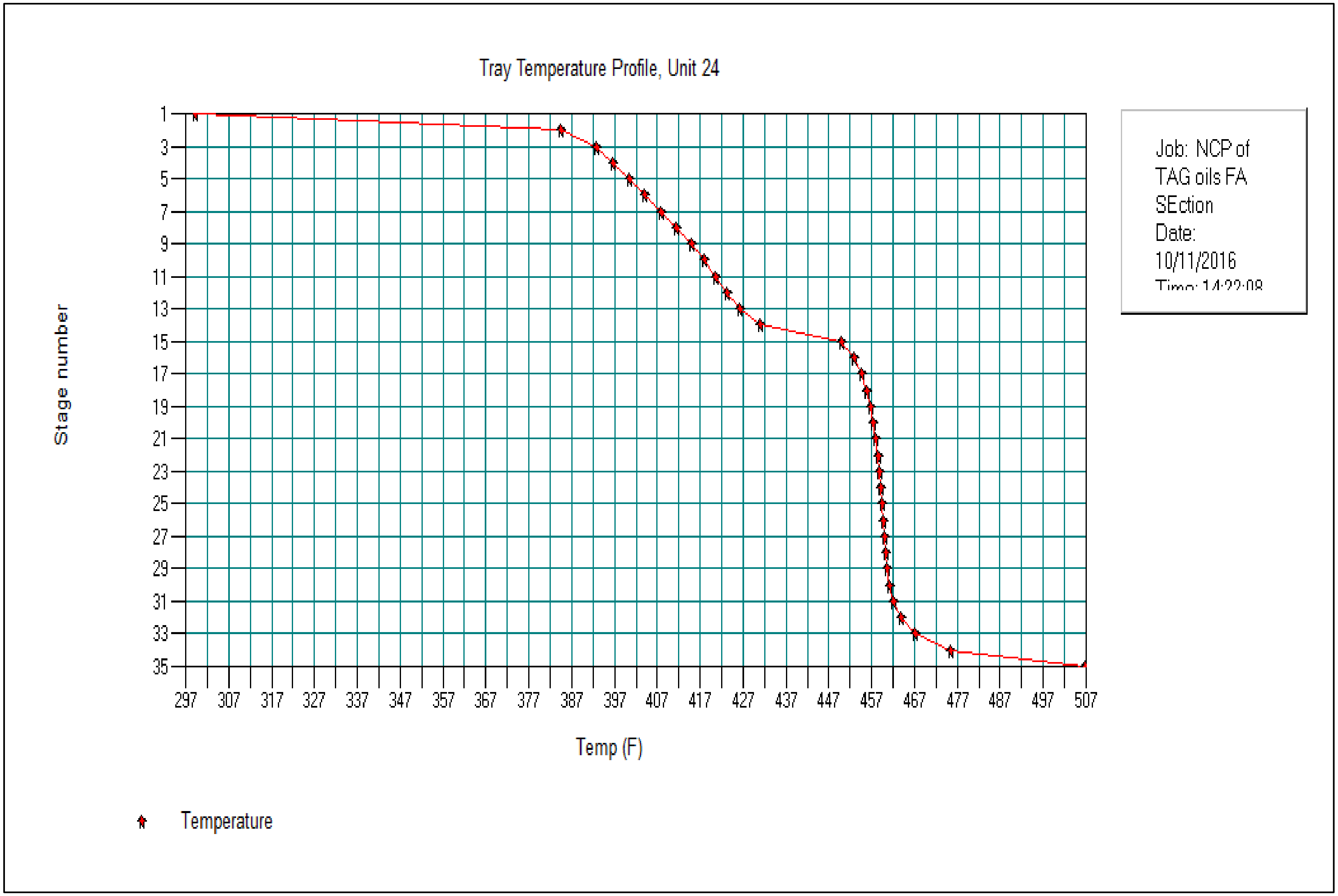
Column temperature profile.

C6-C7 Split Column (D-706)



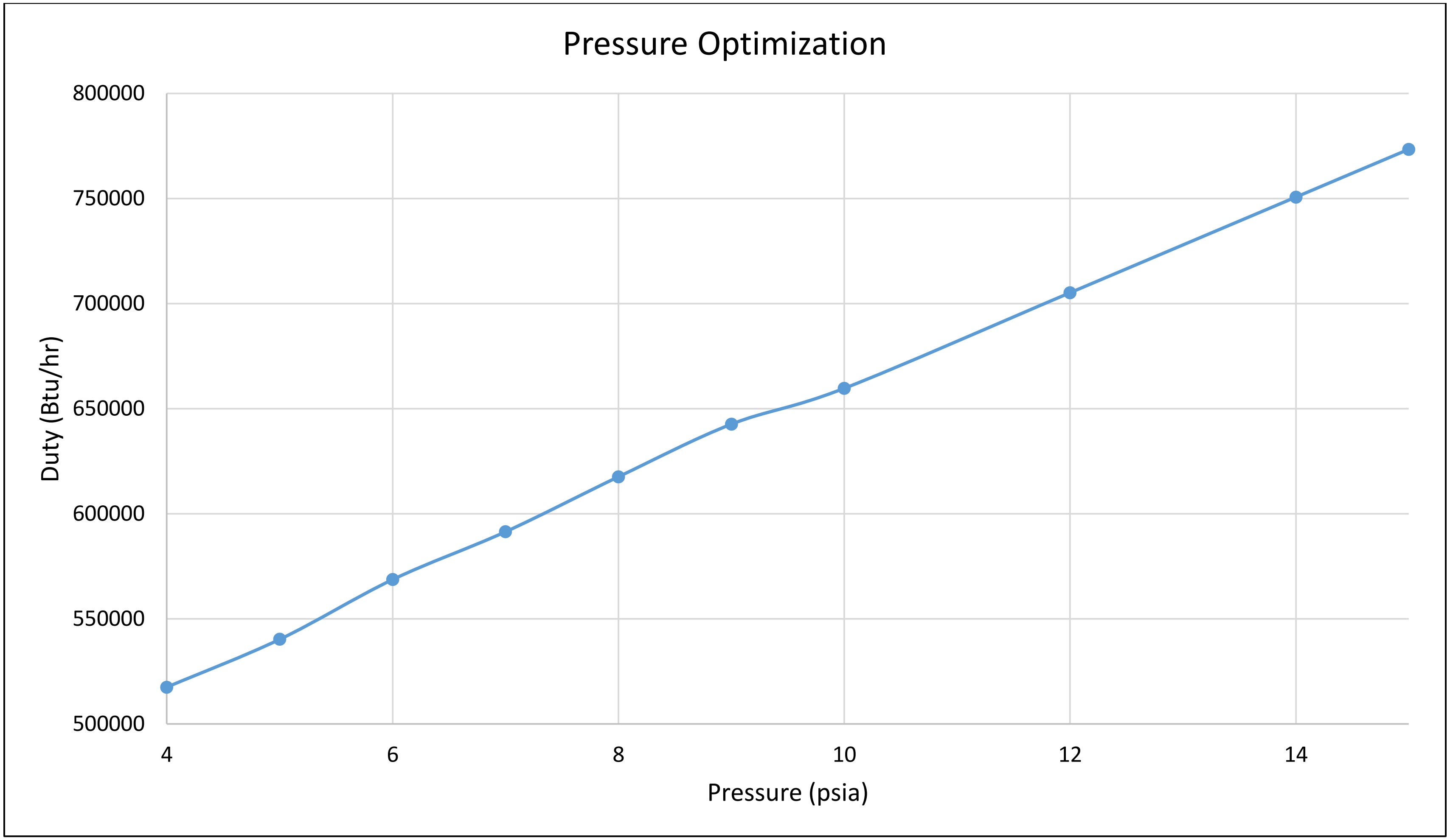


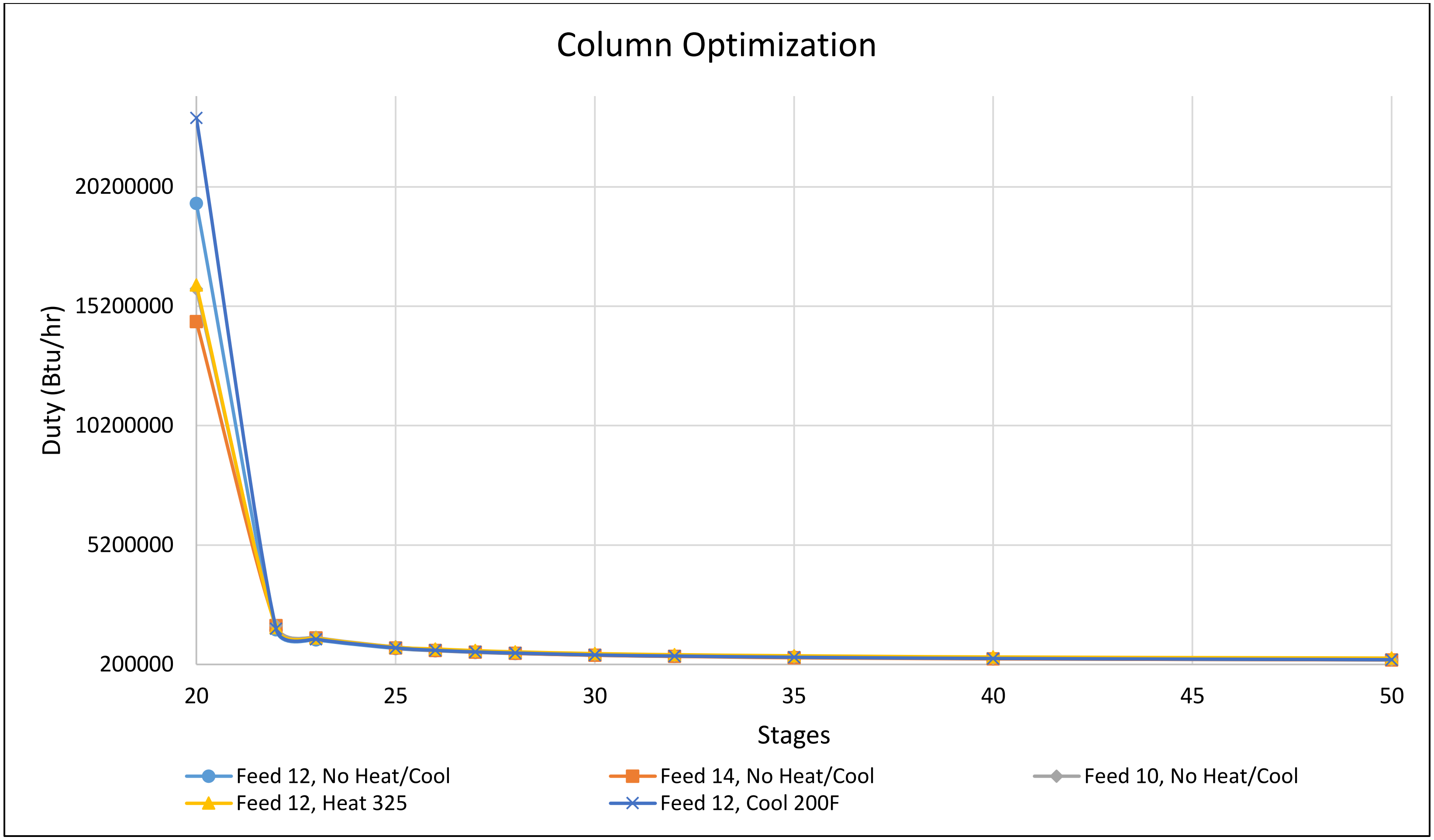
Column Optimization
200000000
150000000
100000000
50000000
0
Duty (Btu/hr)
20
25
30
35
40
45
50
Stages
Feed 10, No Heat/Cool
Feed 15, No heat/Cool
Feed 18, No heat/cool
Feed 15, Cool 400F
Feed 15, Cool 350F
Feed 15, Cool 325F

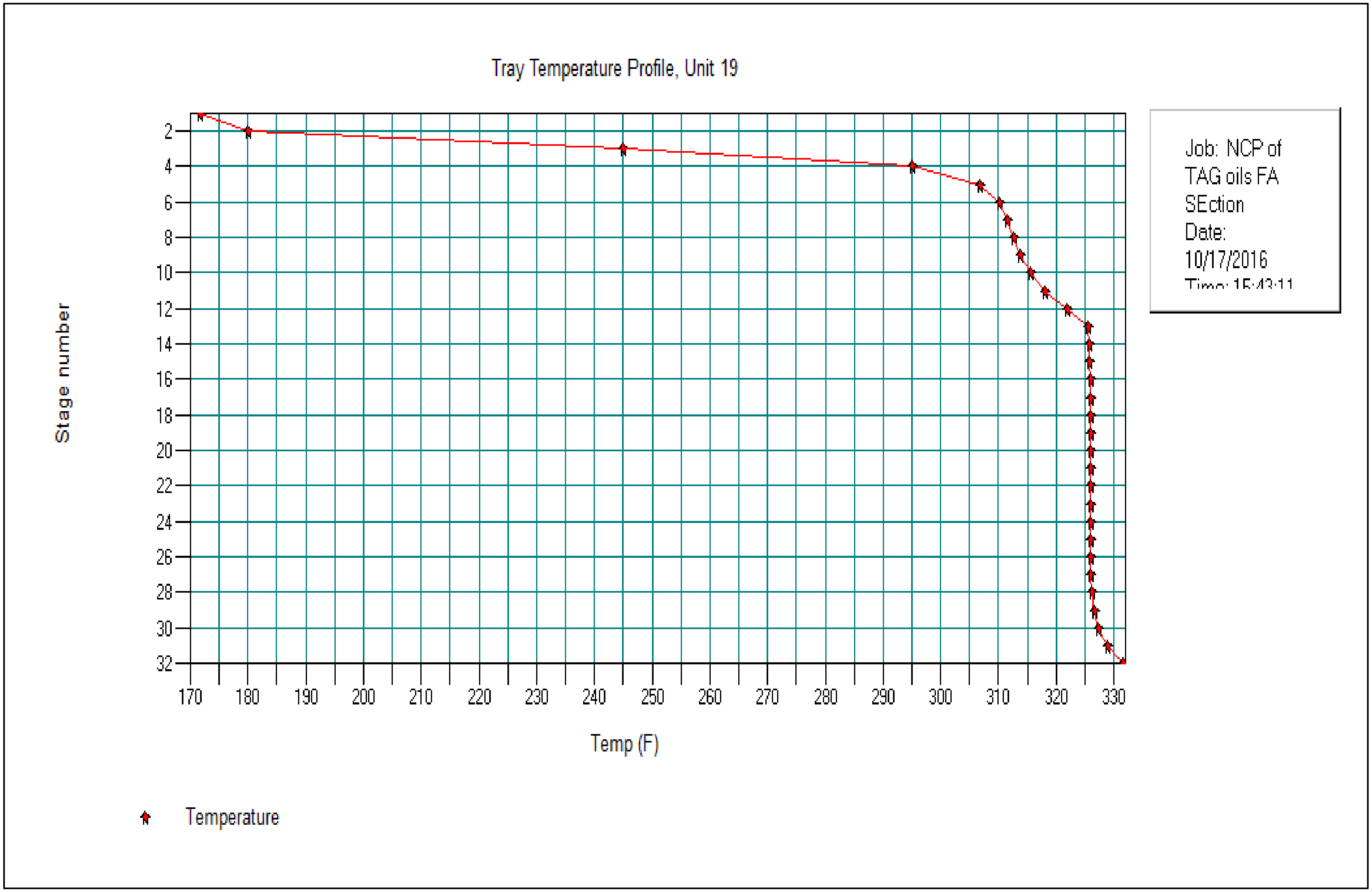


Column temperature profile.

C4-C5 Split Column (D-707)

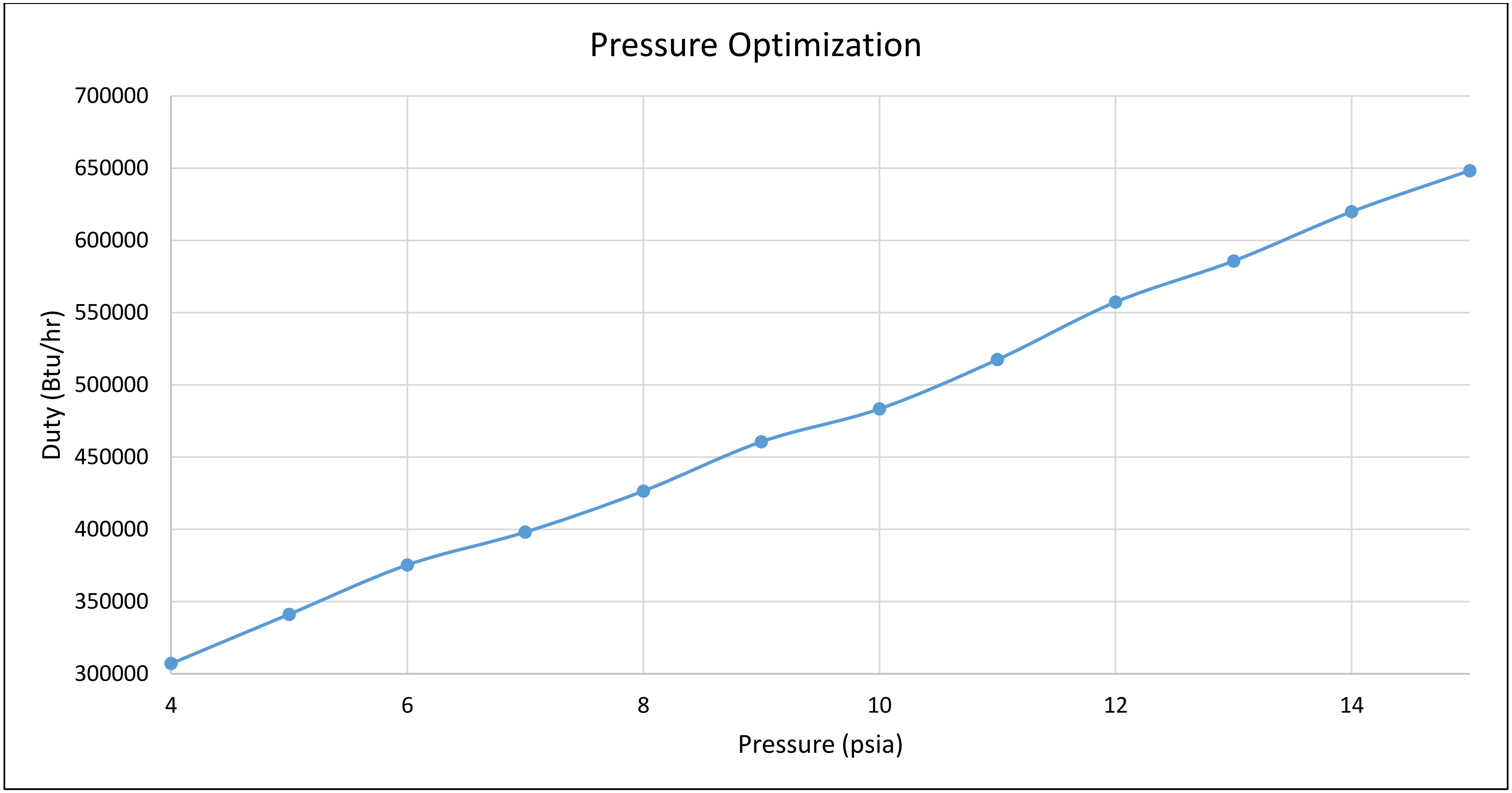


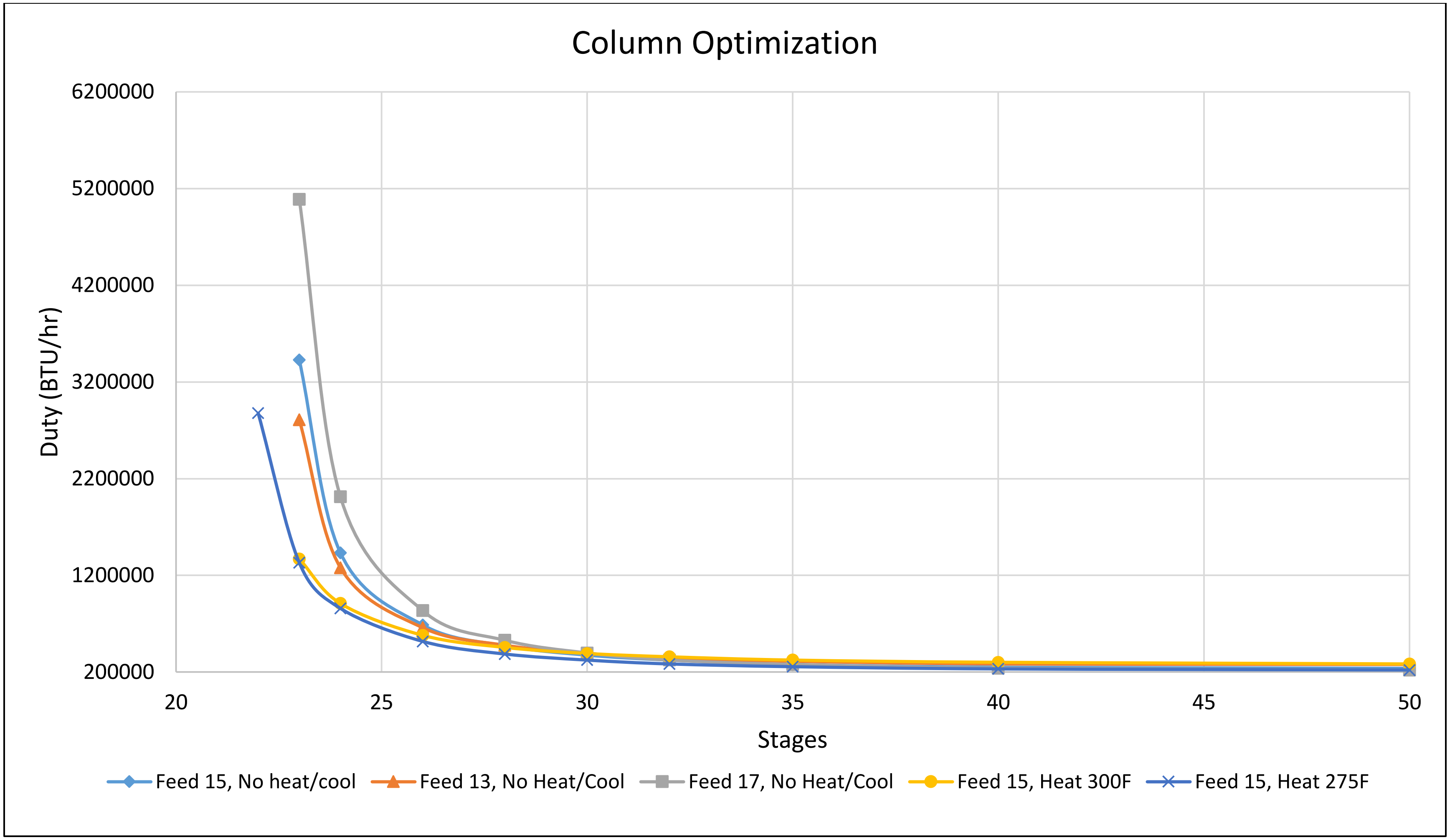

Column Optimization
Duty (Btu/hr)
20200000
15200000
10200000
5200000
200000
20
25
30
35
40
45
50
Stages
Feed 12, No Heat/Cool
Feed 14, No Heat/Cool
Feed 10, No Heat/Cool
Feed 12, Heat 325
Feed 12, Cool 200F



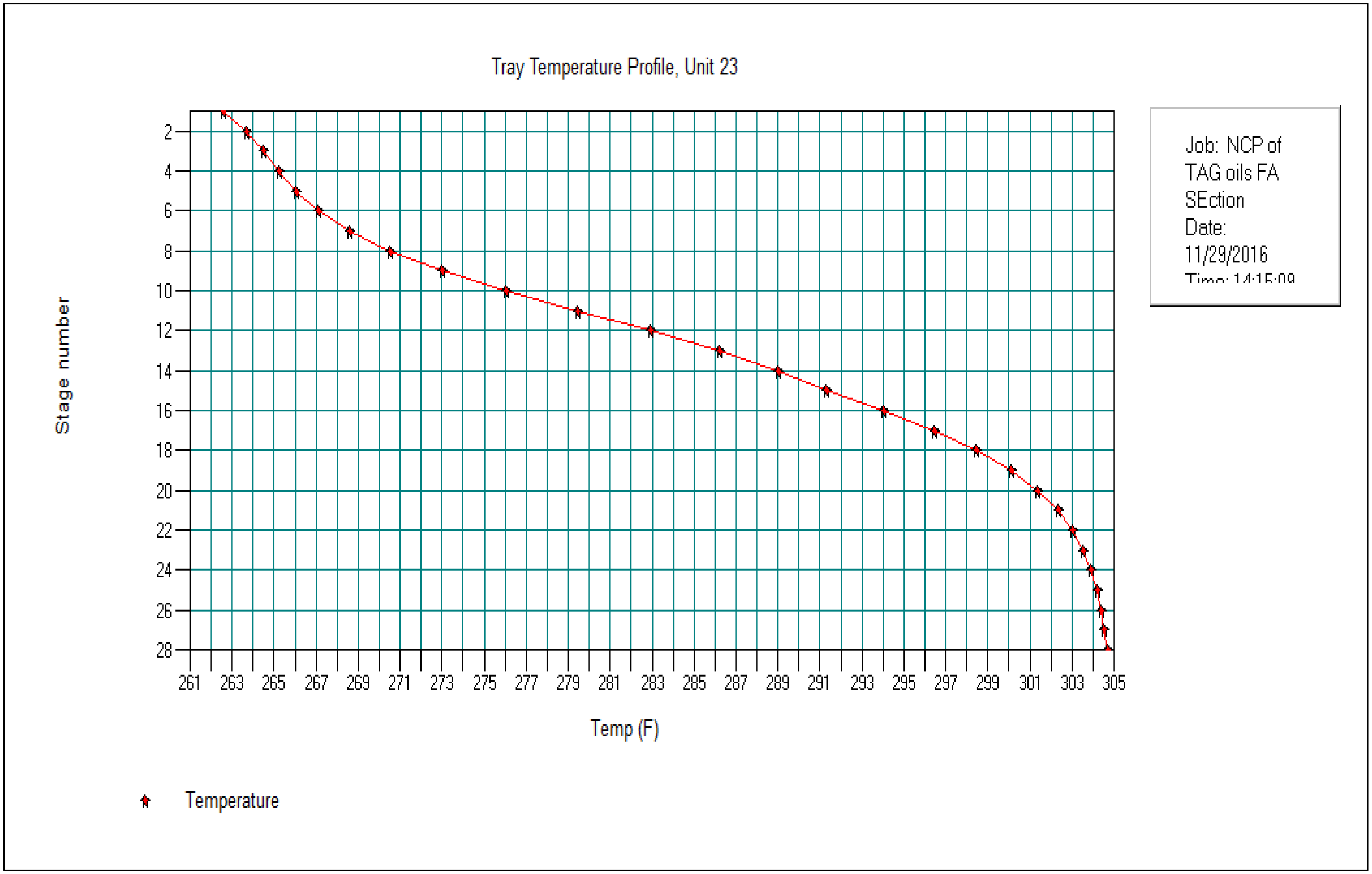
Column temperature profile.

C3-C4 Product Column (D-708)



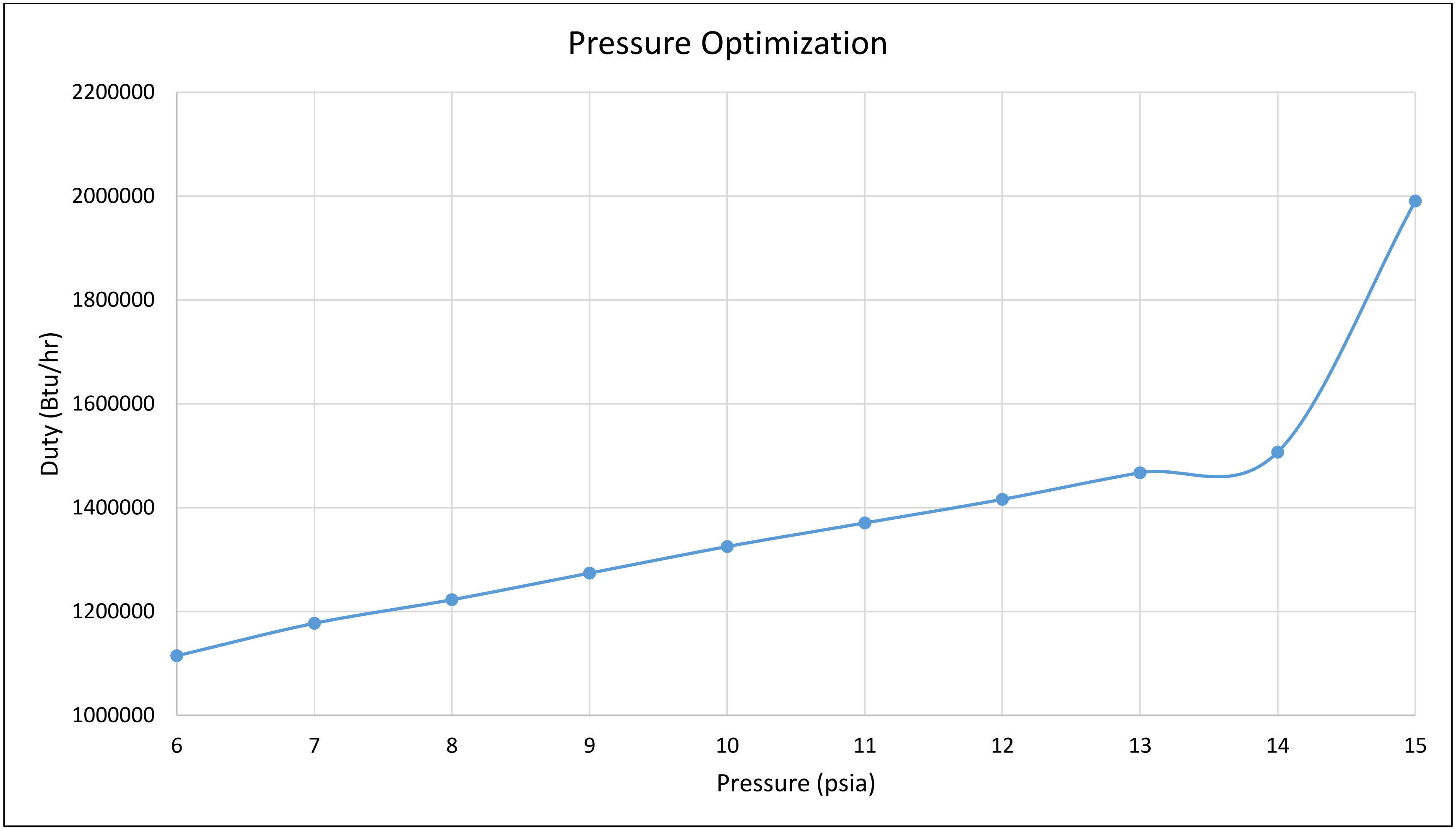


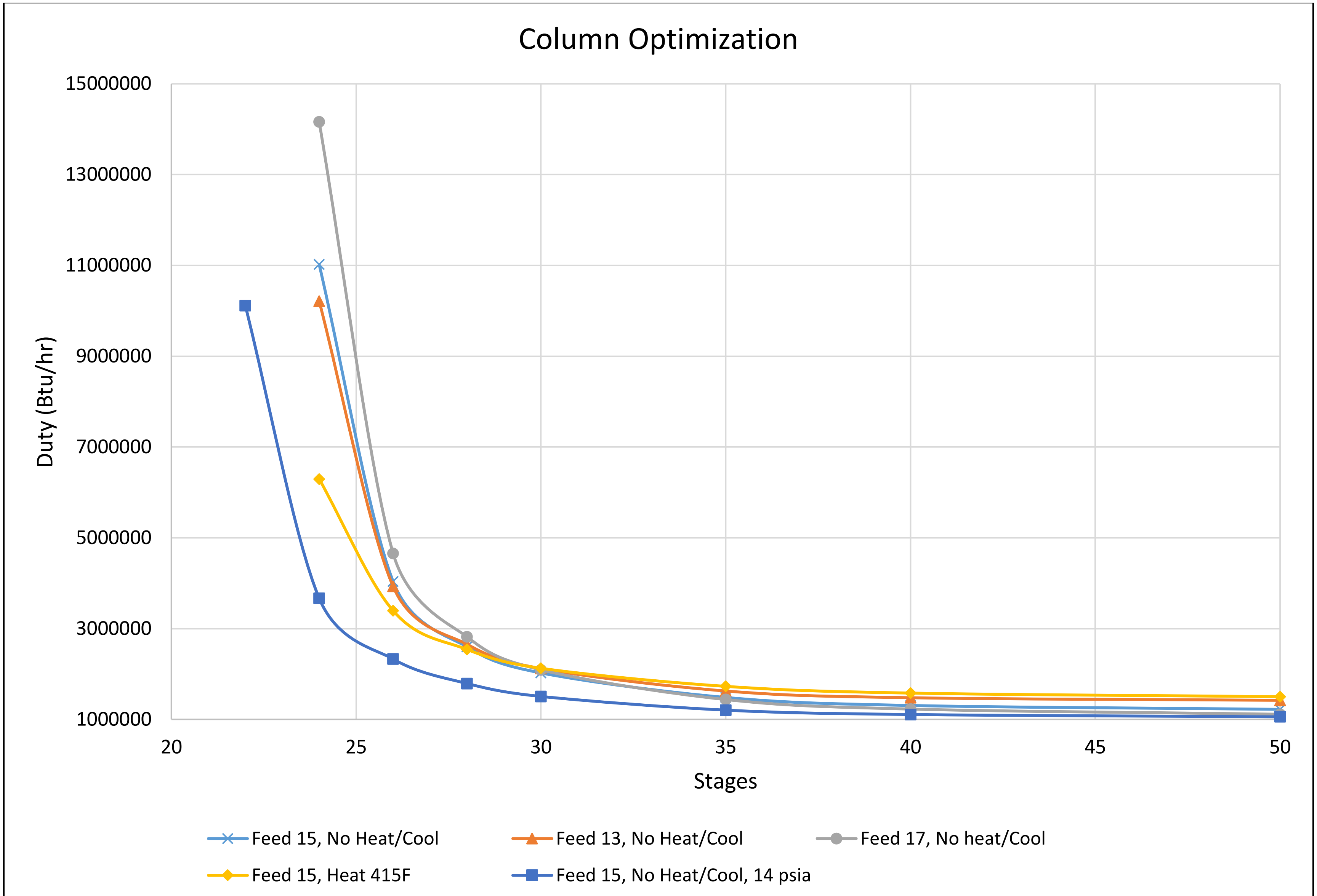
Column Optimization
6200000
5200000
4200000
3200000
2200000
1200000
200000
Duty (BTU/hr)
20
25
30
35
40
45
50
Stages
Feed 15, No heat/cool
Feed 13, No Heat/Cool
Feed 17, No Heat/Cool
Feed 15, Heat 300F
Feed 15, Heat 275F



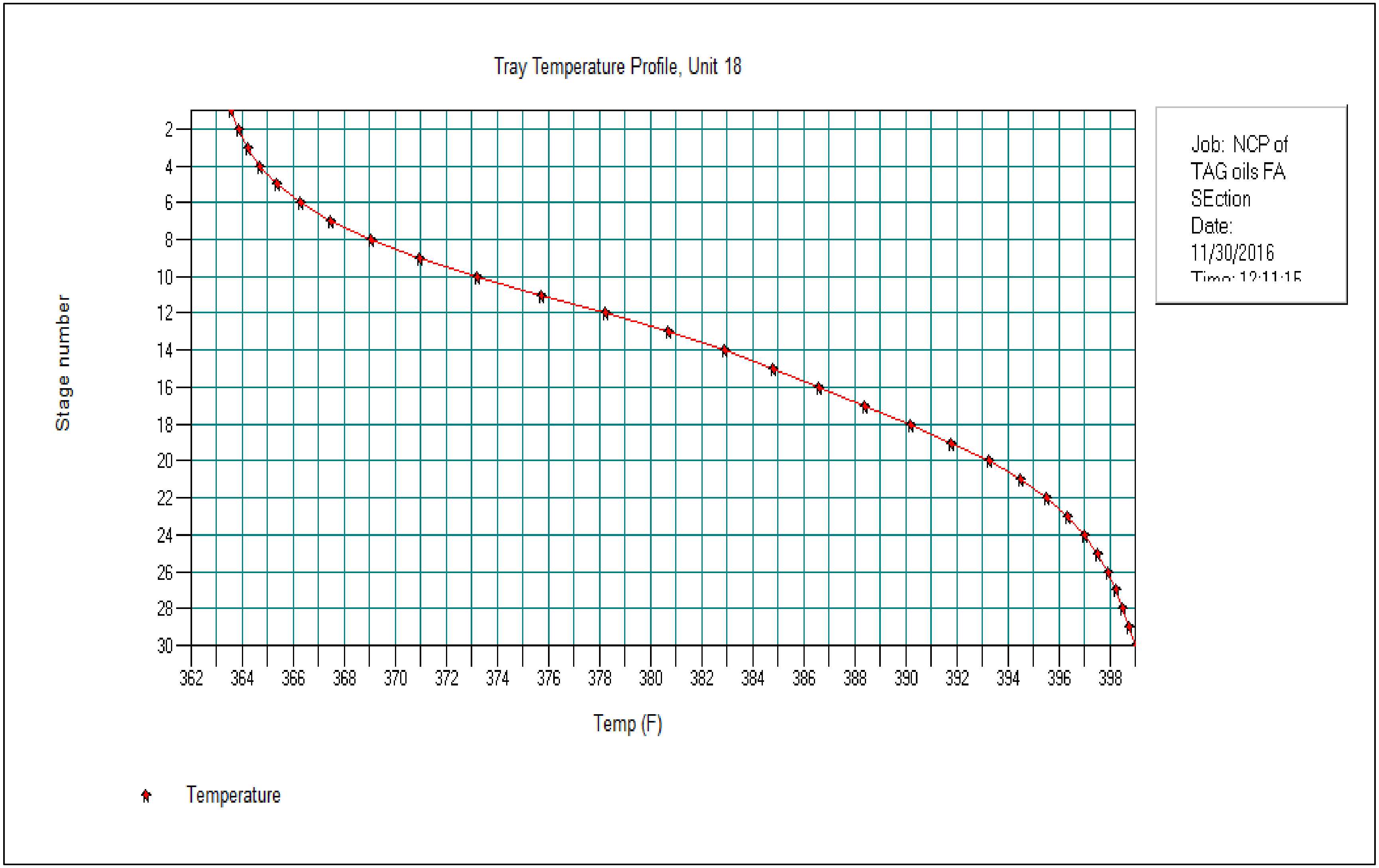
Column temperature profile.

C5-C6 Product Column (D-709)



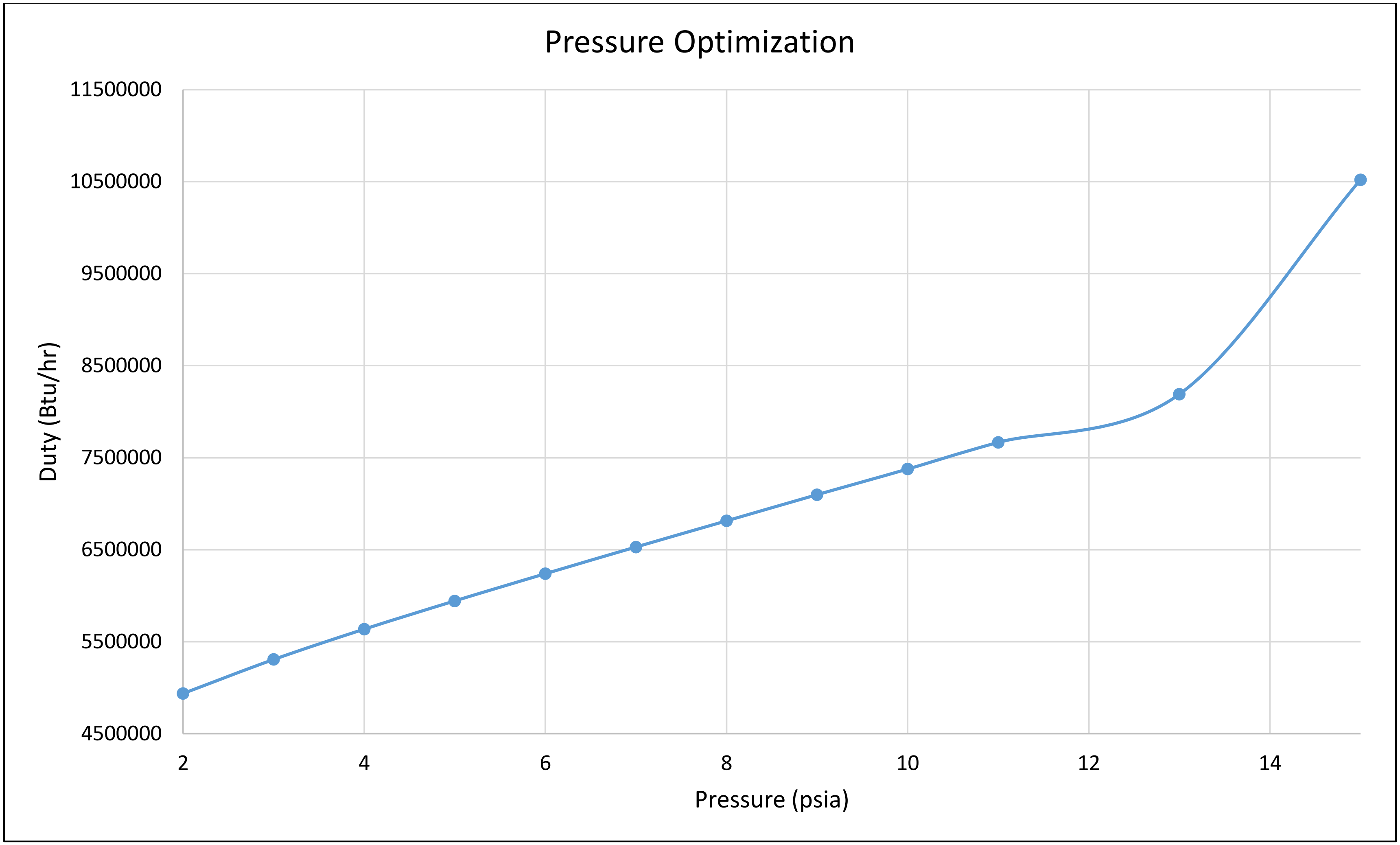


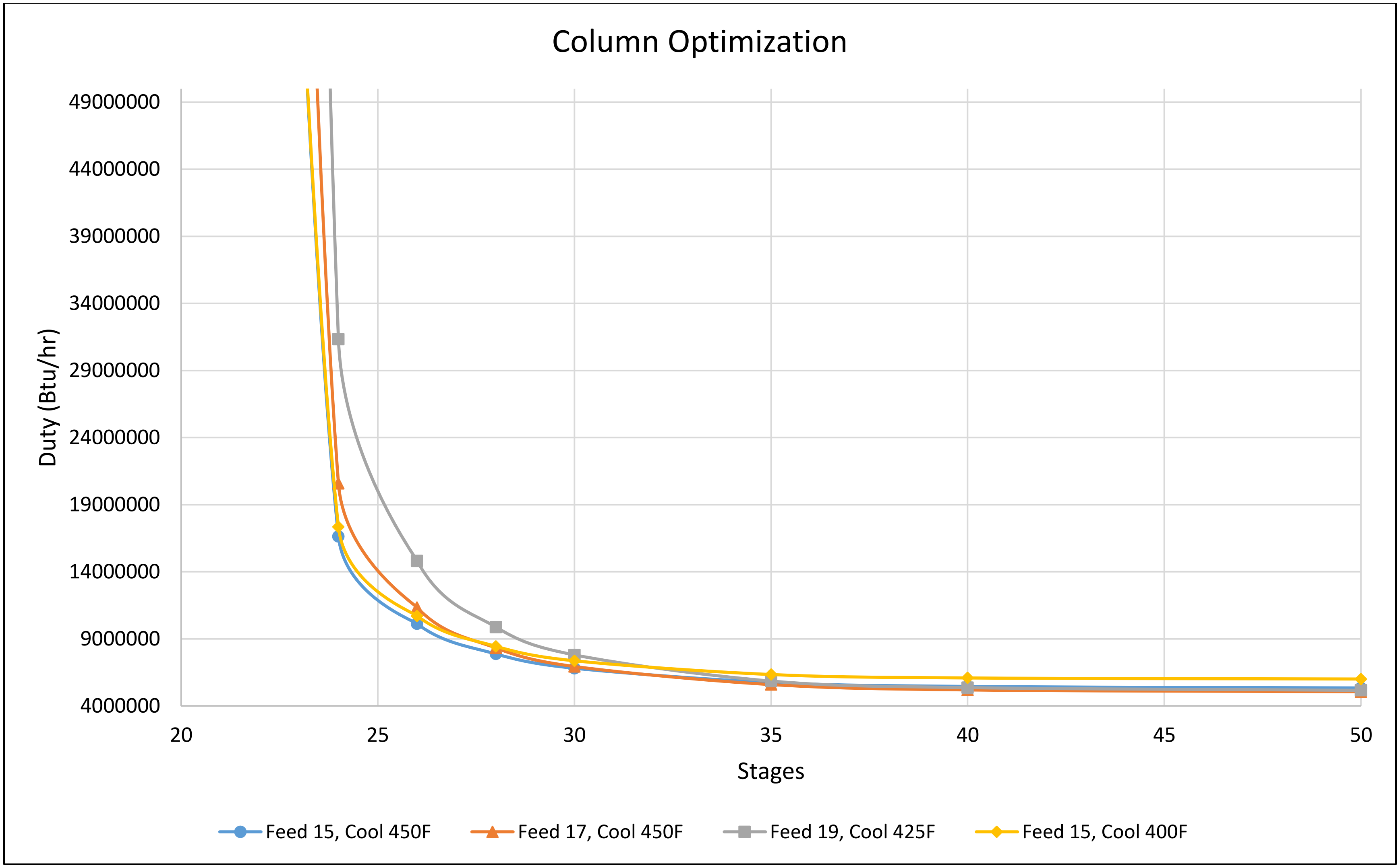
Column Optimization
15000000
13000000
11000000
9000000
7000000
5000000
3000000
1000000
Duty (Btu/hr)
20
25
30
35
40
45
50
Stages
Feed 15, No Heat/Cool
Feed 13, No Heat/Cool
Feed 17, No heat/Cool
Feed 15, Heat 415F
Feed 15, No Heat/Cool, 14 psia

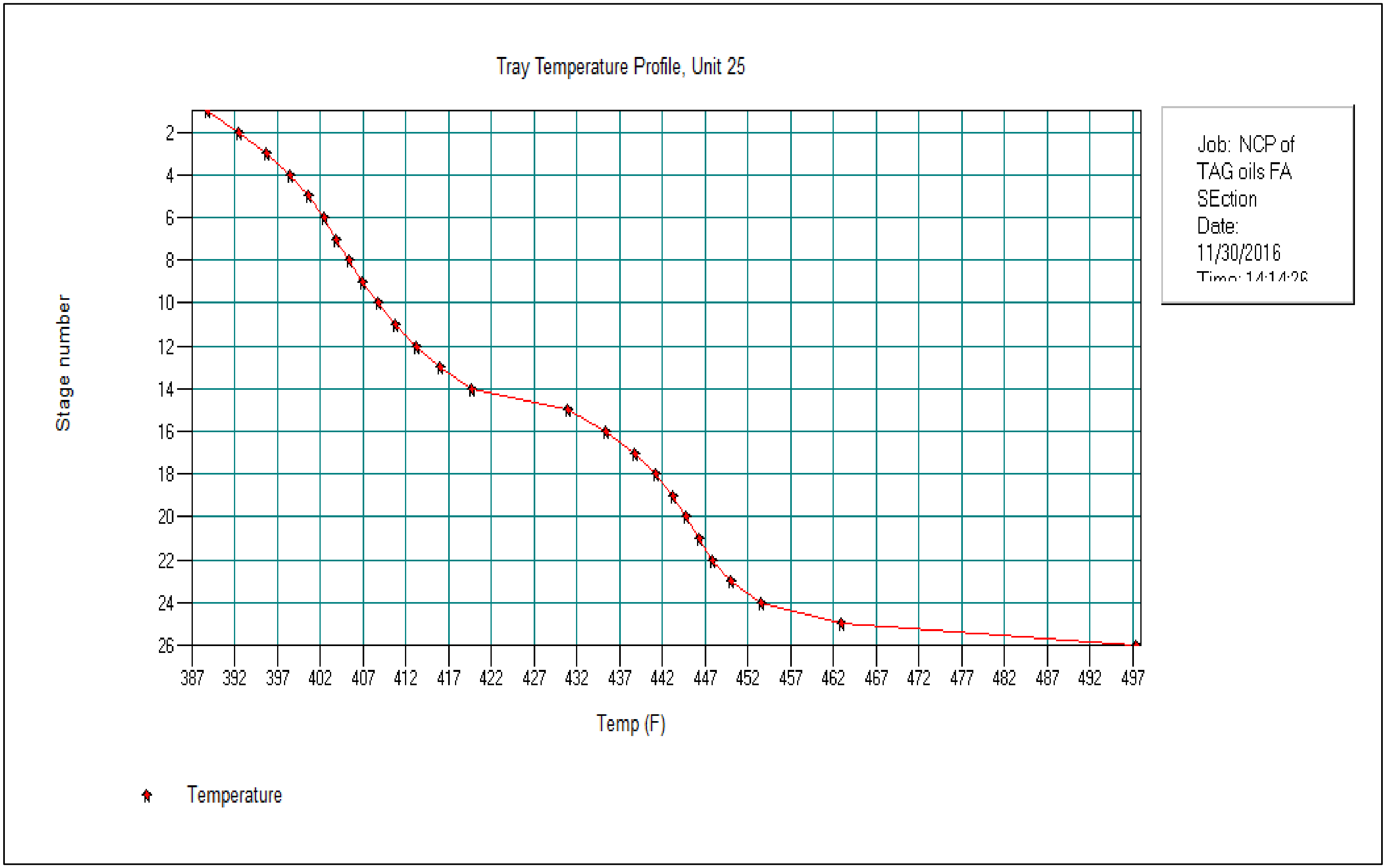


Column temperature profile.

C8-C9 Split Column (D-710)

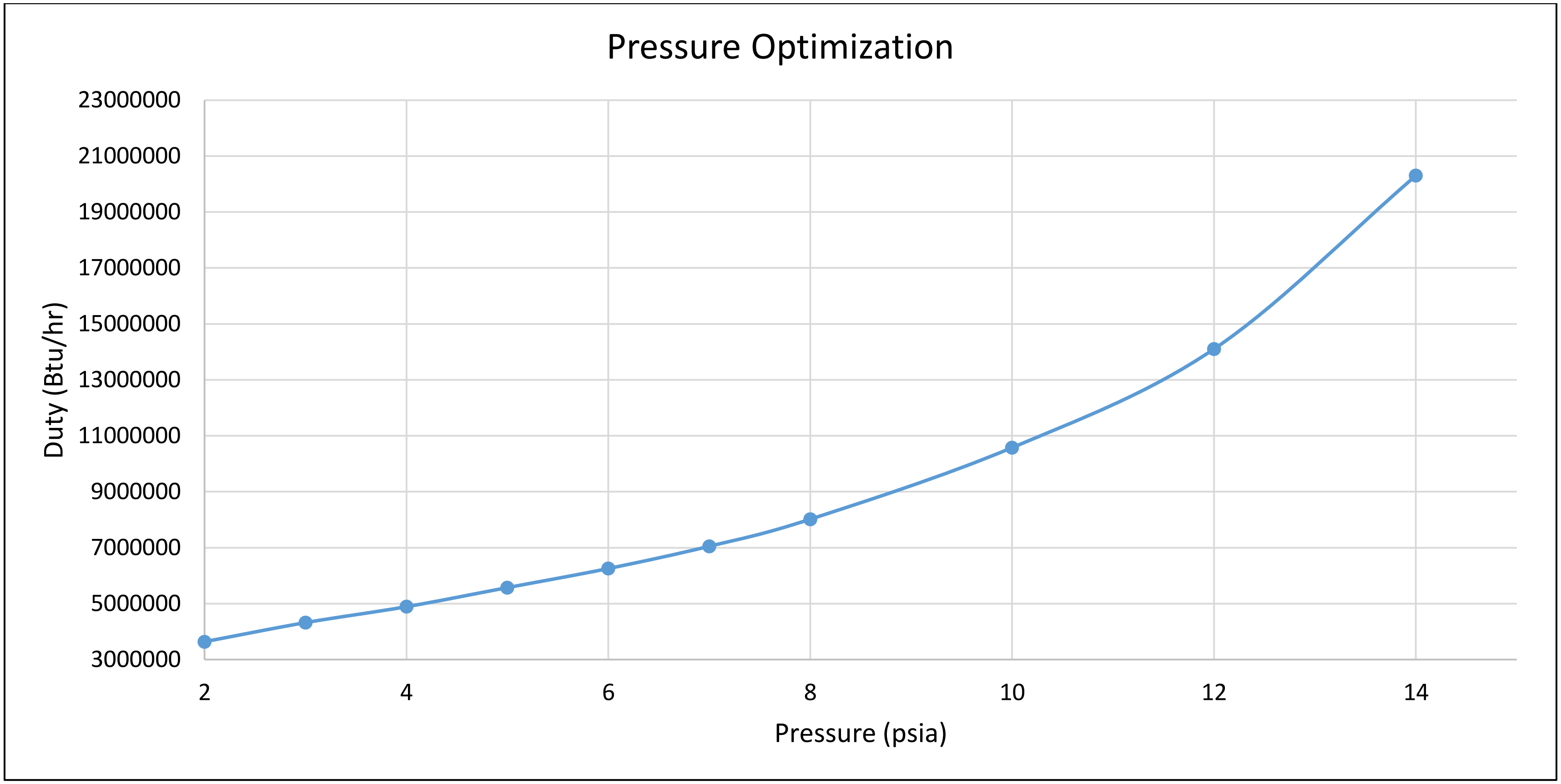


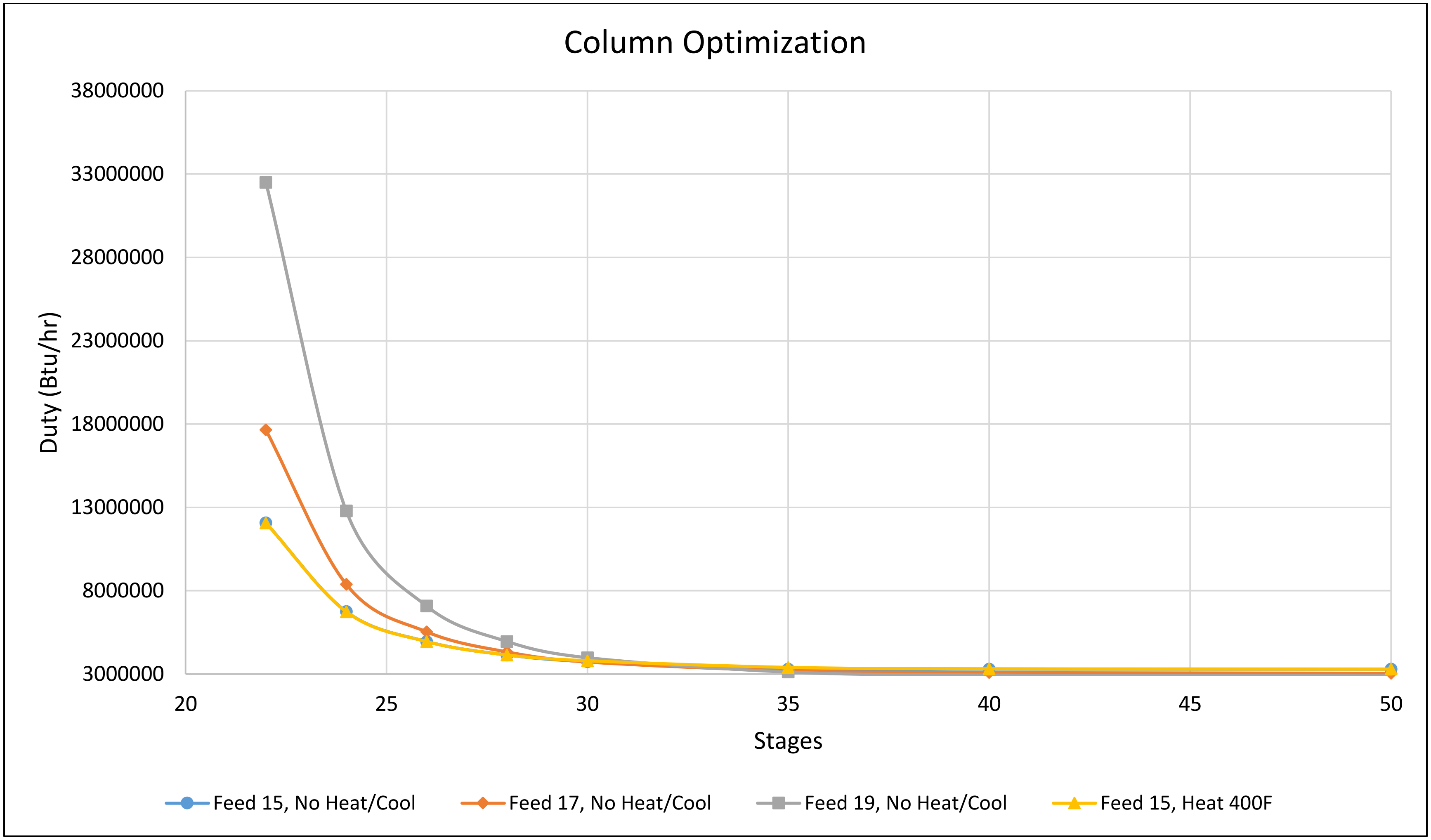

Column Optimization
Duty (Btu/hr)
49000000
44000000
39000000
34000000
29000000
24000000
19000000
14000000
9000000
4000000
20
25
30
35
40
45
50
Stages
Feed 15, Cool 450F
Feed 17, Cool 450F
Feed 19, Cool 425F
Feed 15, Cool 400F

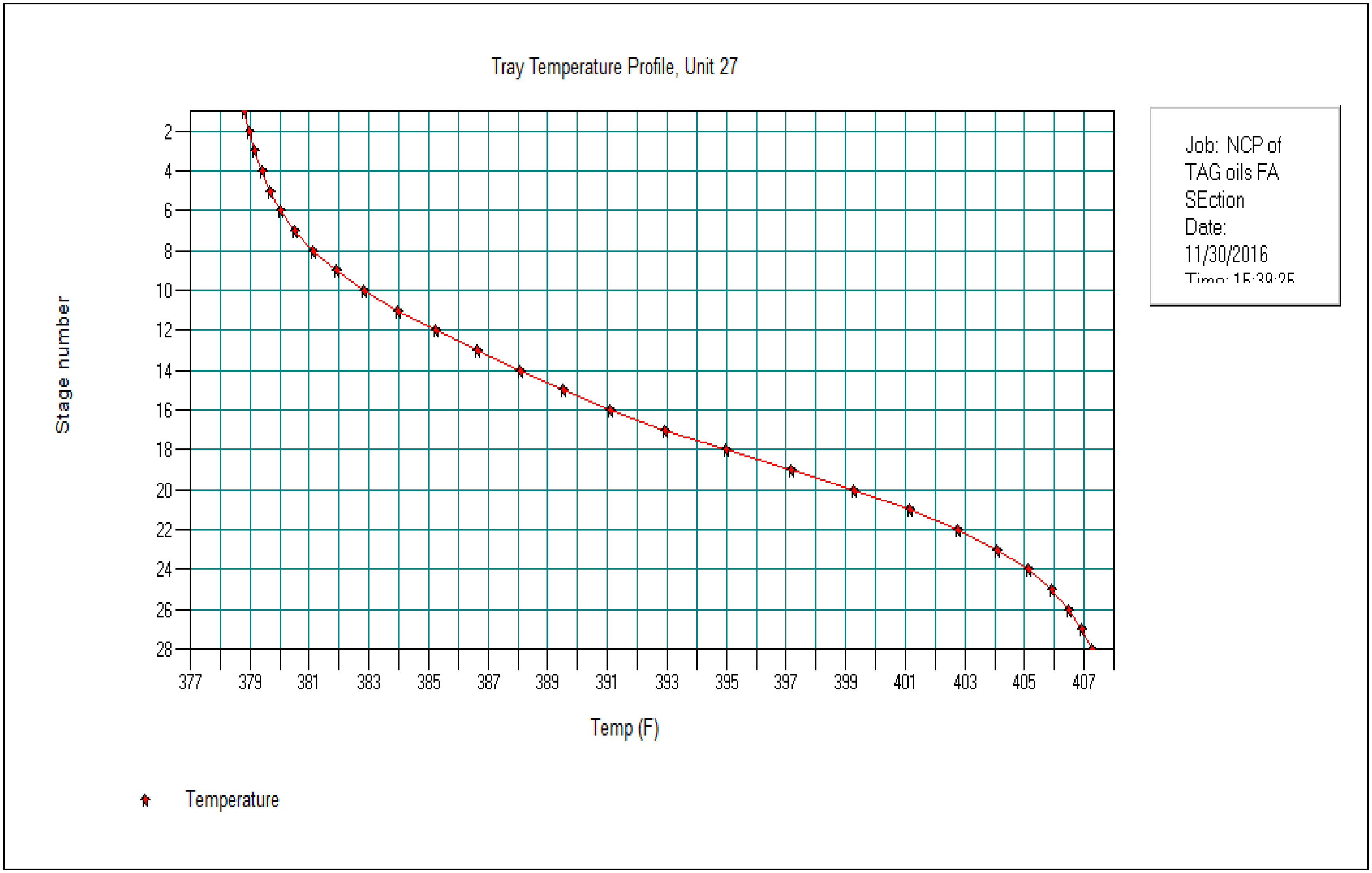


Column temperature profile.

C7-C8 Product Column (D-711)

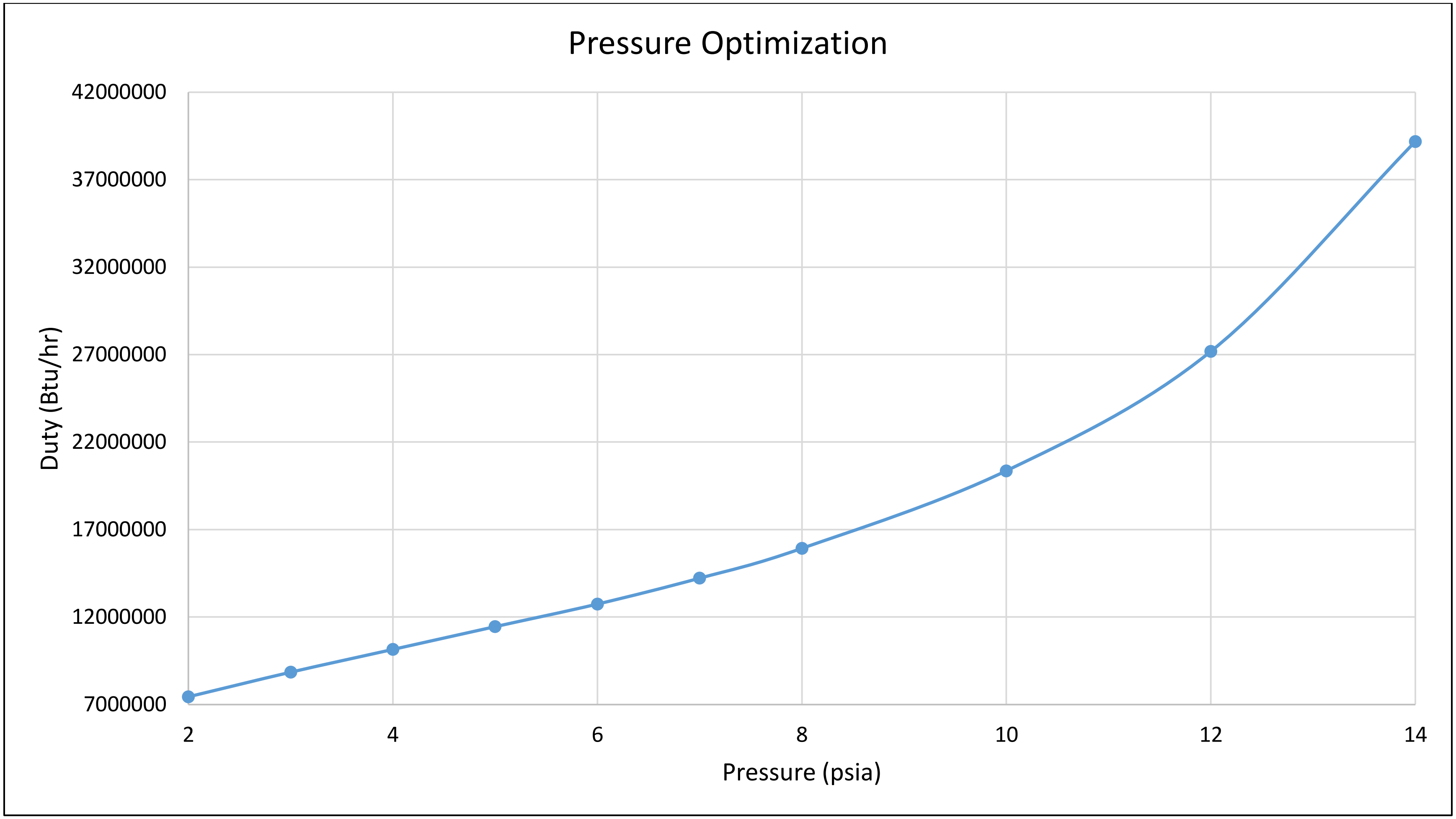


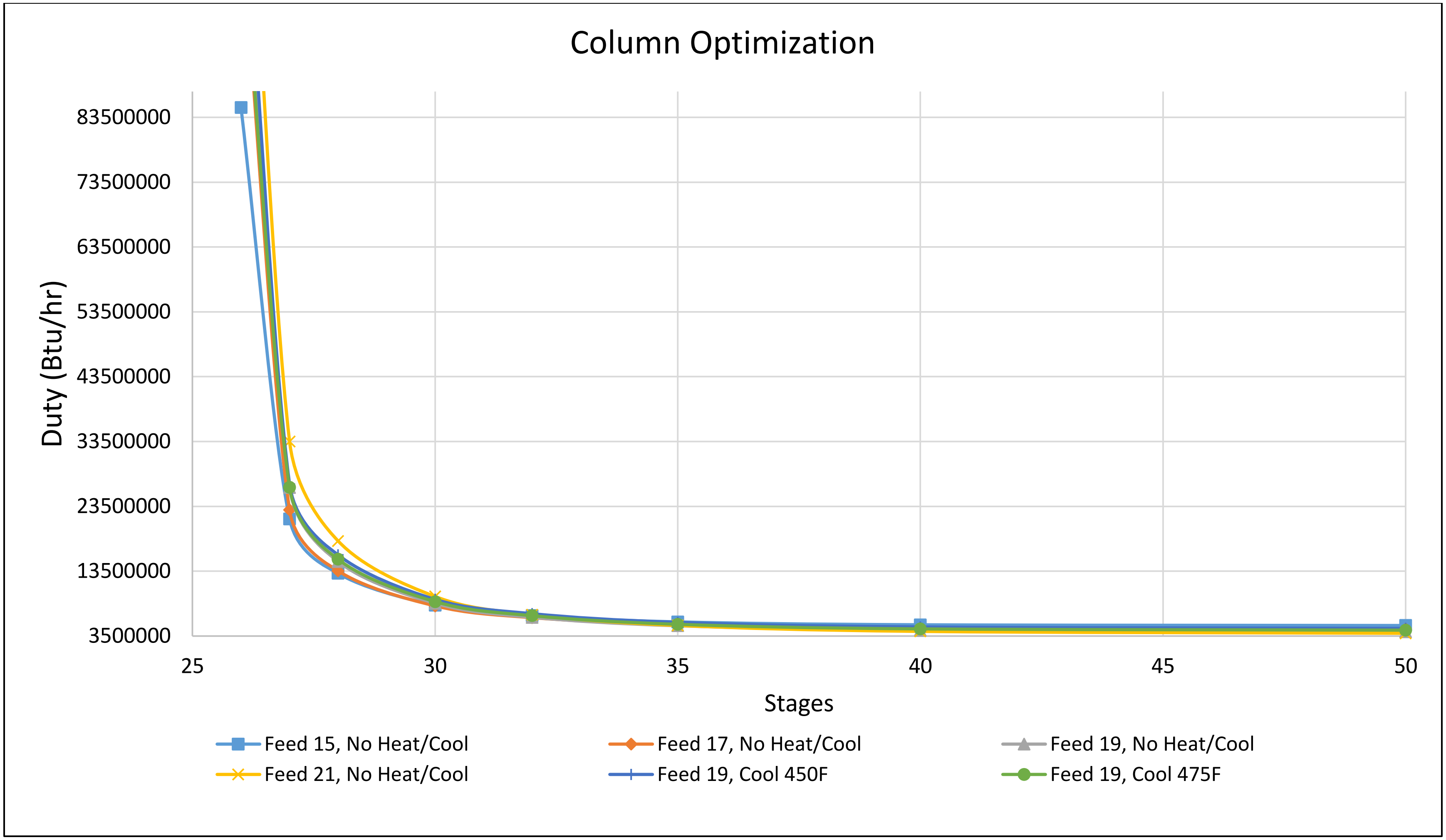

Column Optimization
38000000
33000000
28000000
23000000
18000000
13000000
8000000
3000000
Duty (Btu/hr)
20
25
30
35
40
45
50
Stages
Feed 15, No Heat/Cool
Feed 17, No Heat/Cool
Feed 19, No Heat/Cool
Feed 15, Heat 400F

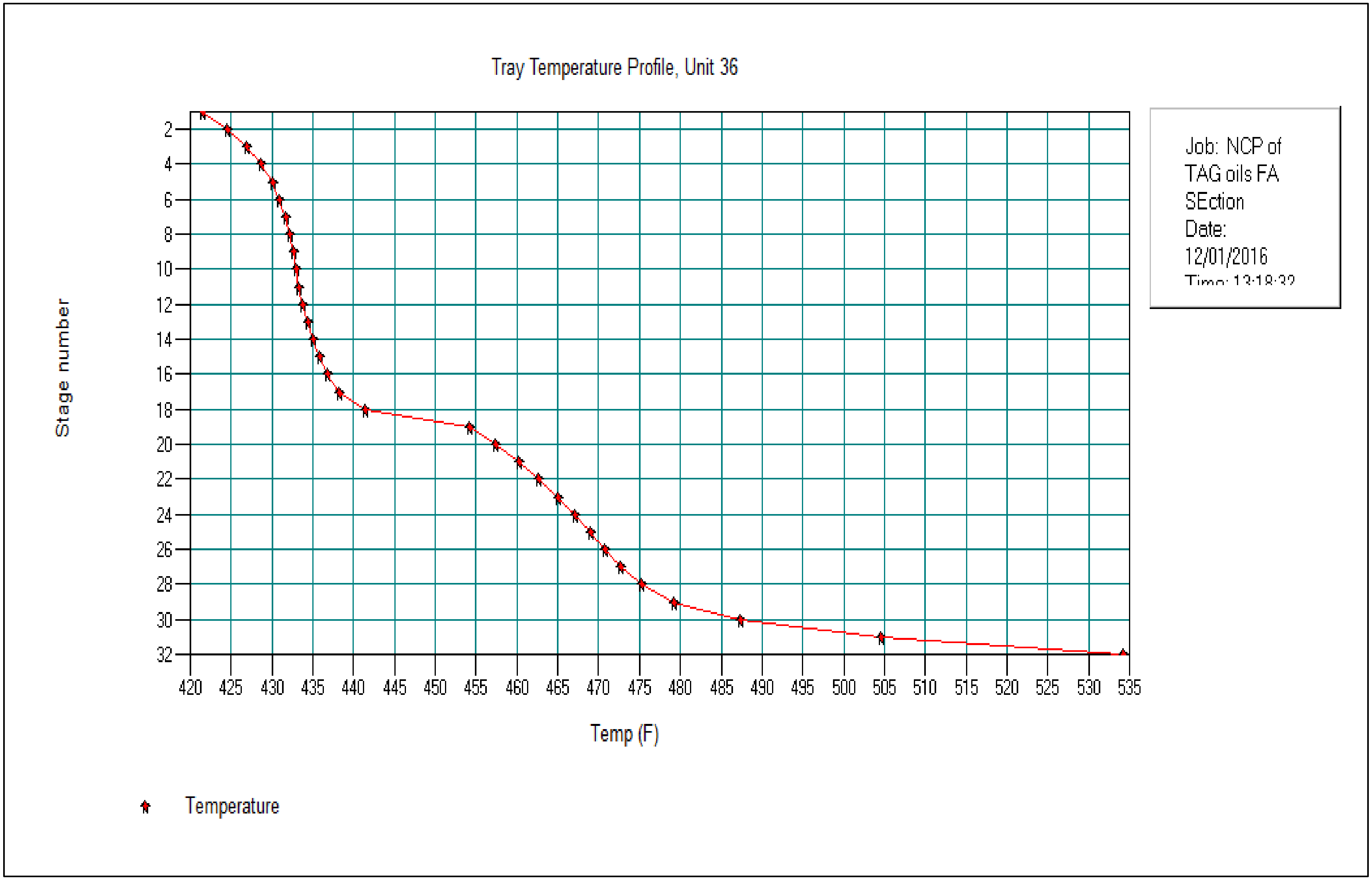


Column temperature profile.

C10-C11 Split Column (D-712)

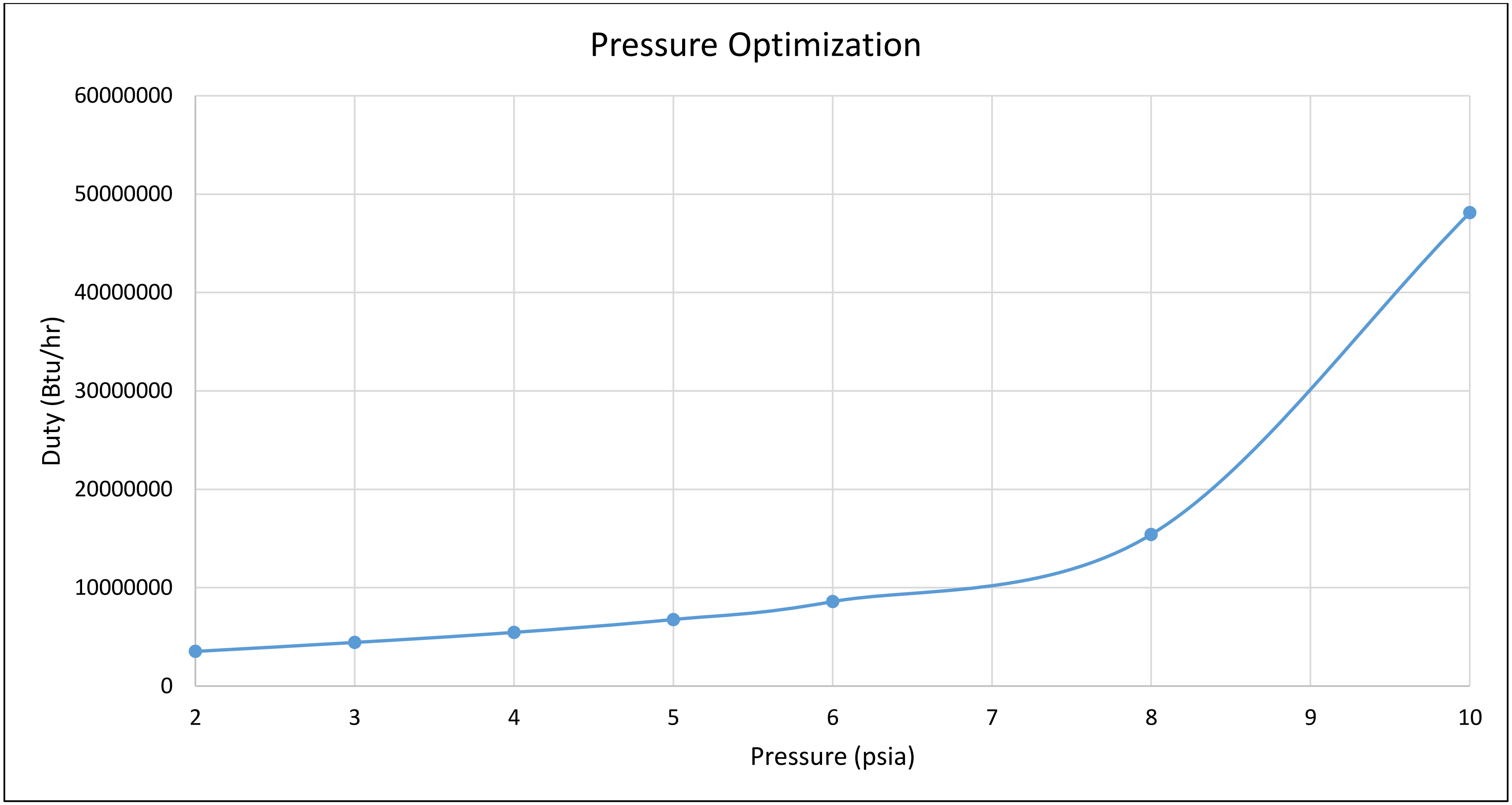


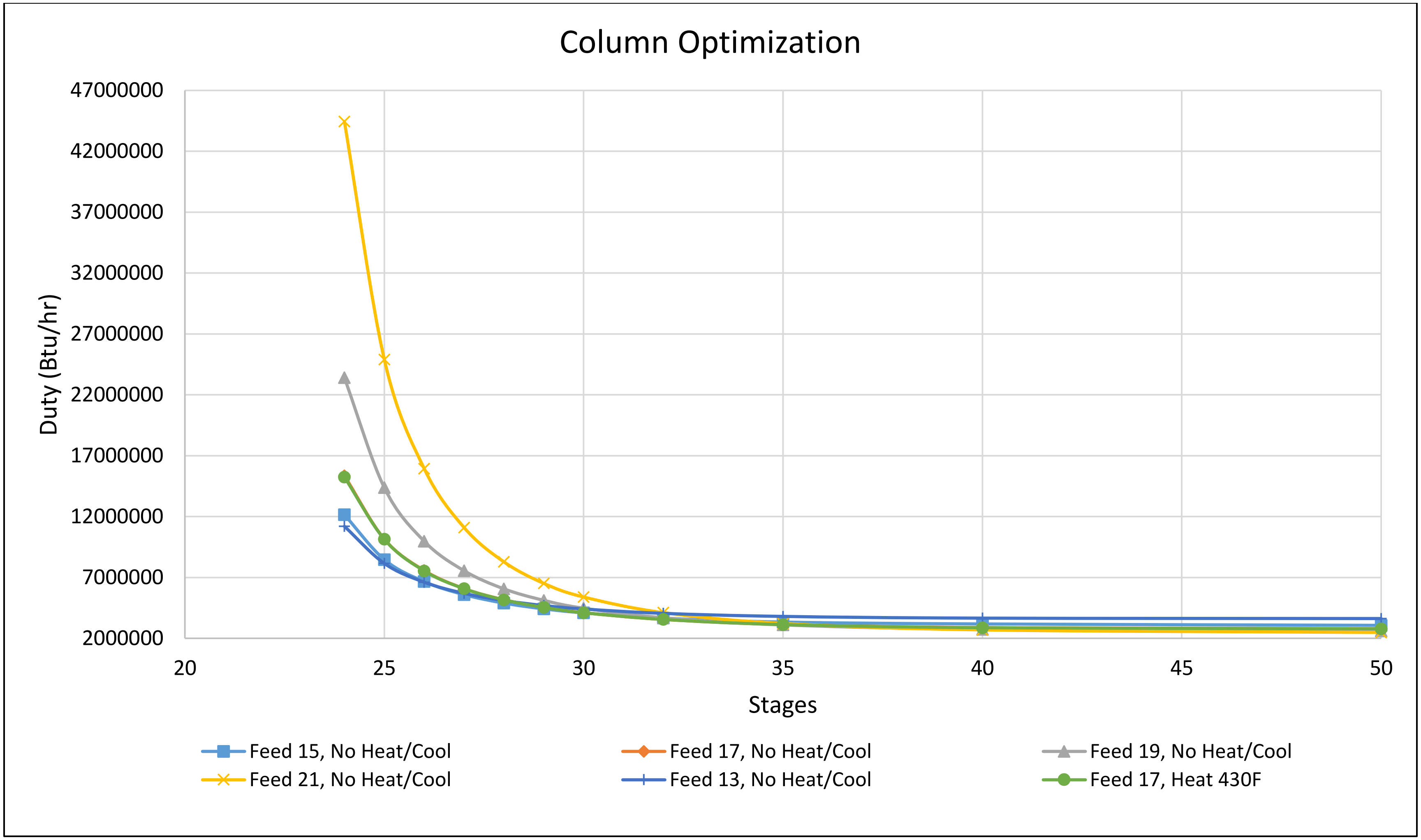

Column Optimization
Duty (Btu/hr)
83500000
73500000
63500000
53500000
43500000
33500000
23500000
13500000
3500000
25
30
35
40
45
50
Stages
Feed 15, No Heat/Cool
Feed 17, No Heat/Cool
Feed 19, No Heat/Cool
Feed 21, No Heat/Cool
Feed 19, Cool 450F
Feed 19, Cool 475F



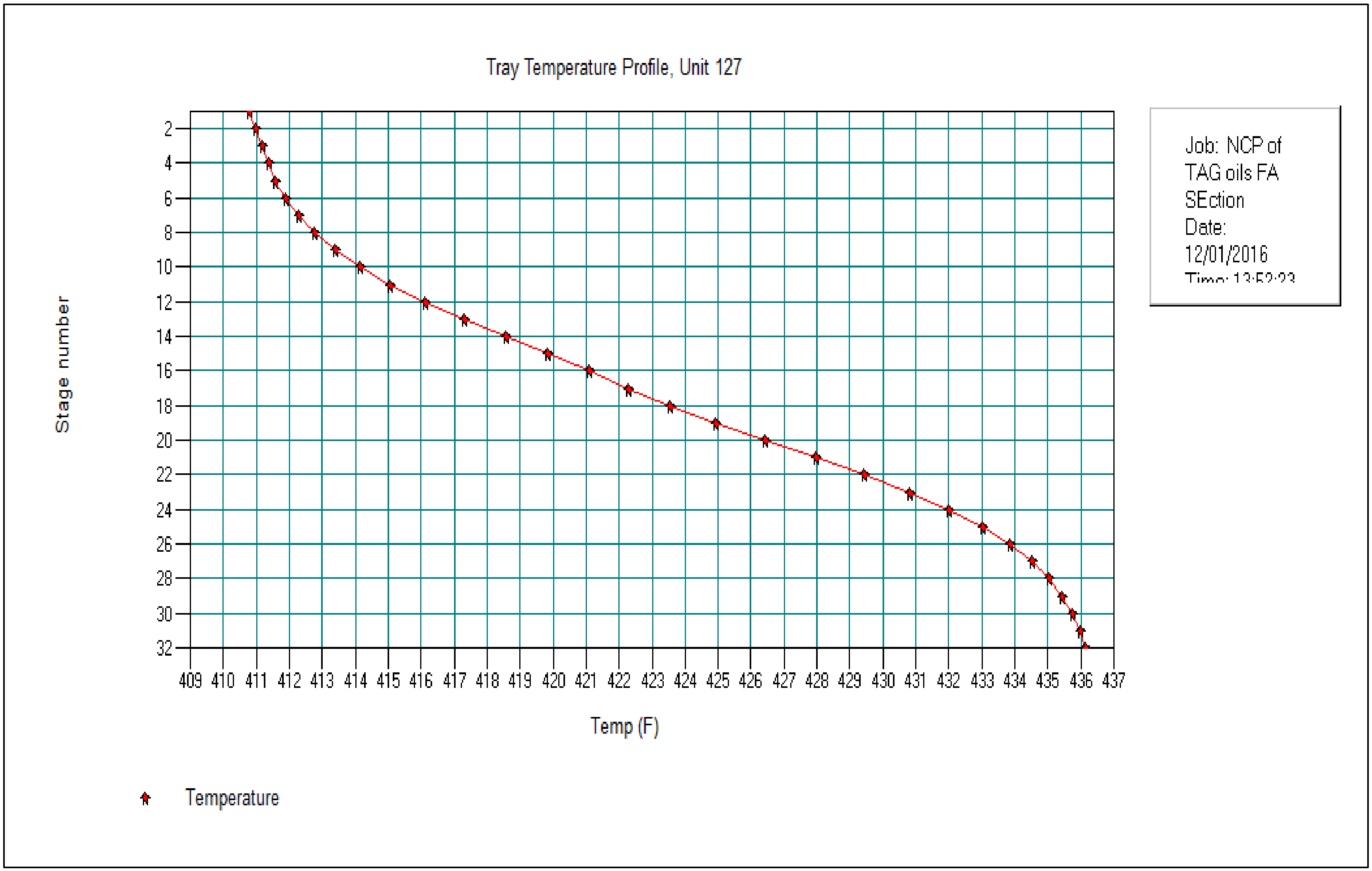
Column temperature profile.

C9-C10 Product Column (D-713)



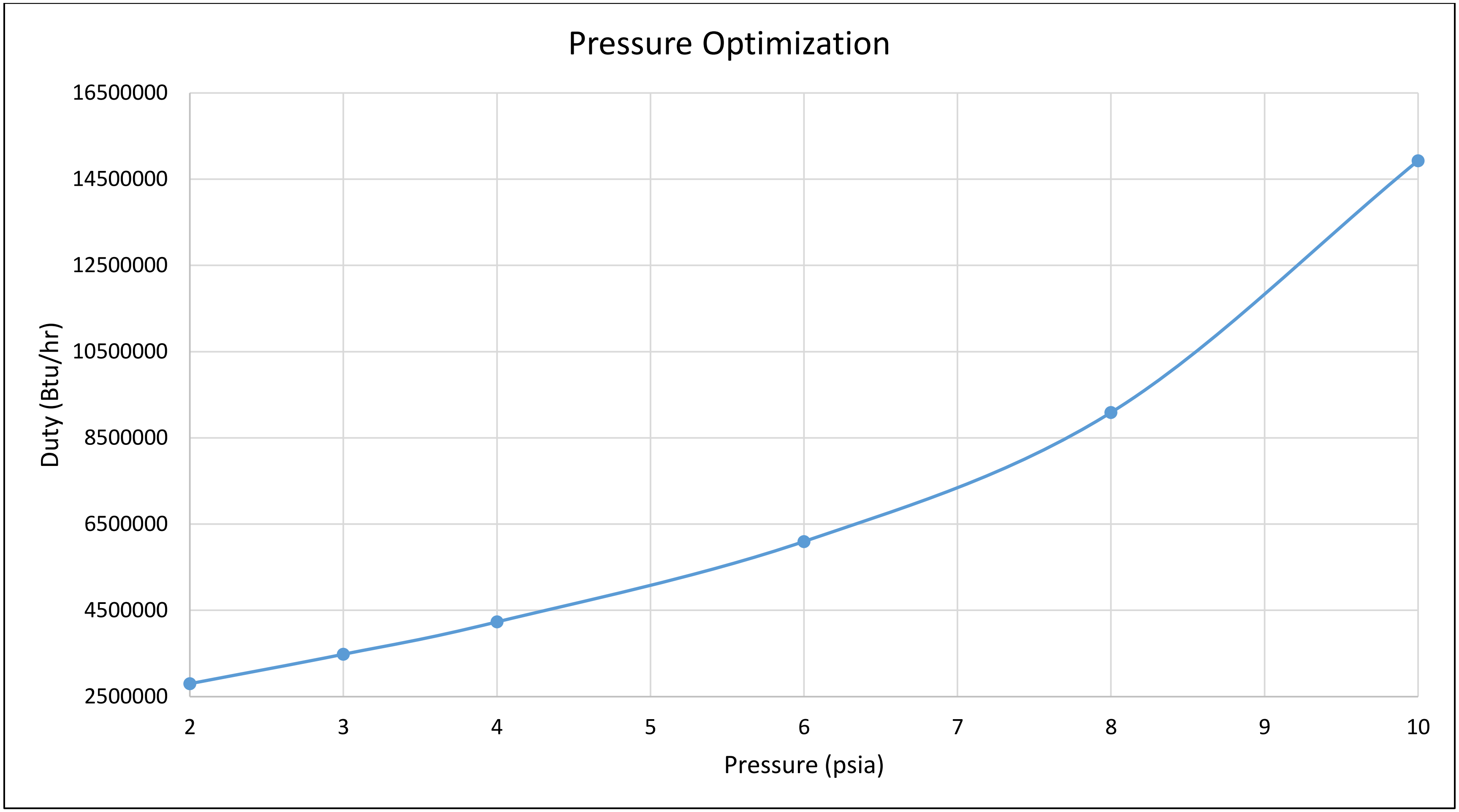


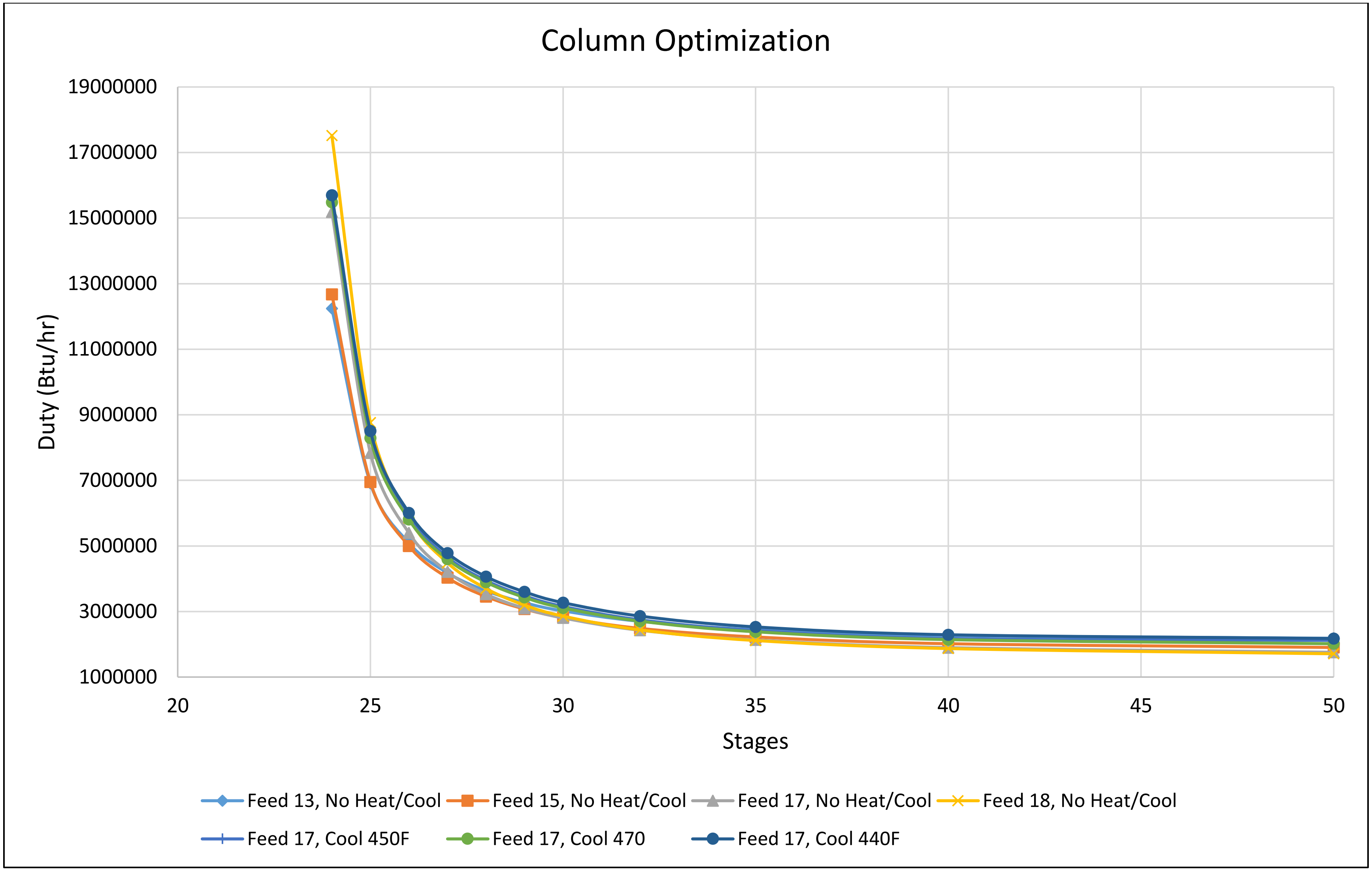
Column Optimization
Duty (Btu/hr)
47000000
42000000
37000000
32000000
27000000
22000000
17000000
12000000
7000000
2000000
20
25
30
35
40
45
50
Stages
Feed 15, No Heat/Cool
Feed 17, No Heat/Cool
Feed 19, No Heat/Cool
Feed 21, No Heat/Cool
Feed 13, No Heat/Cool
Feed 17, Heat 430F

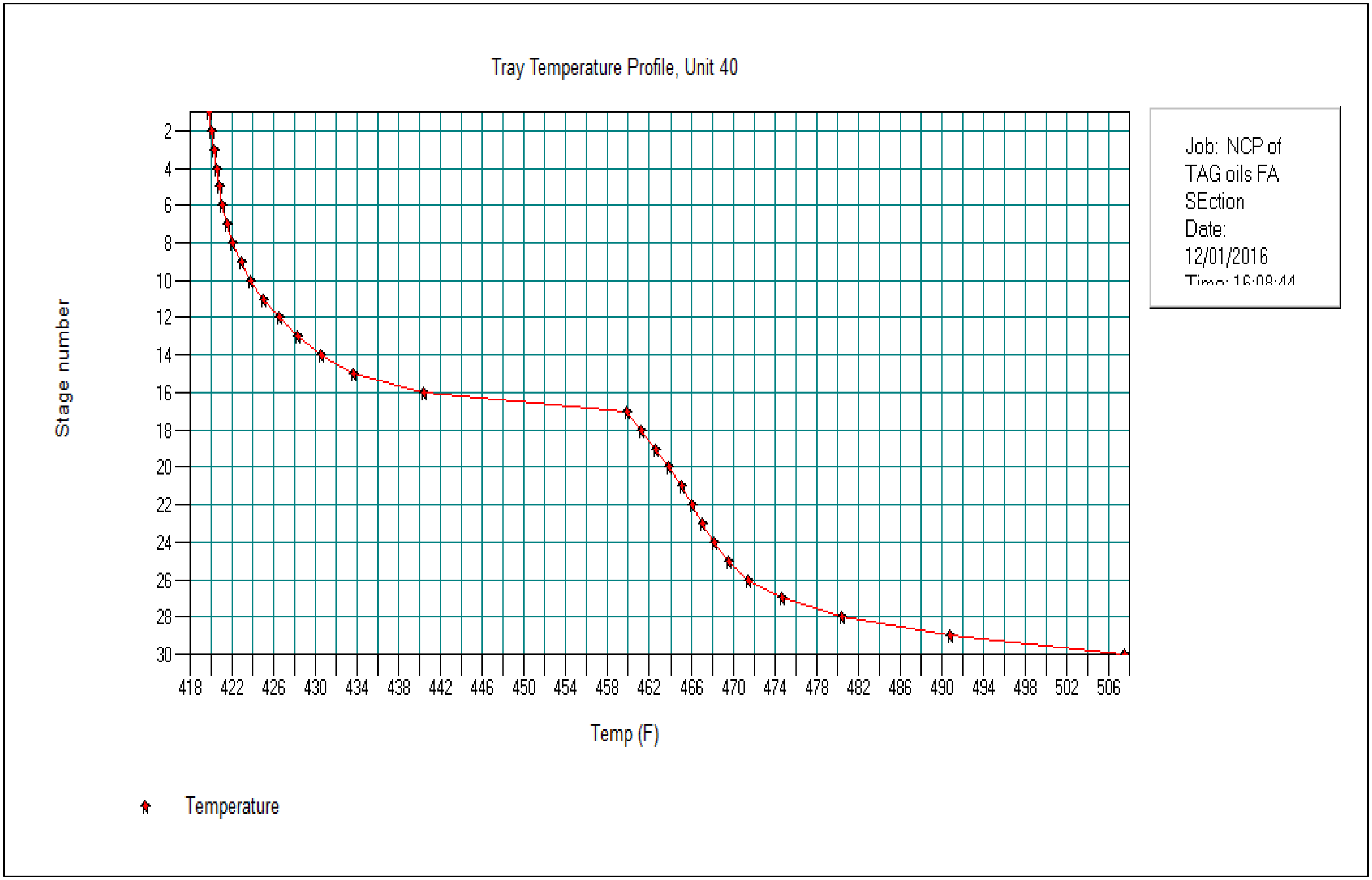


Column temperature profile.

C11 Product Column (D-714)

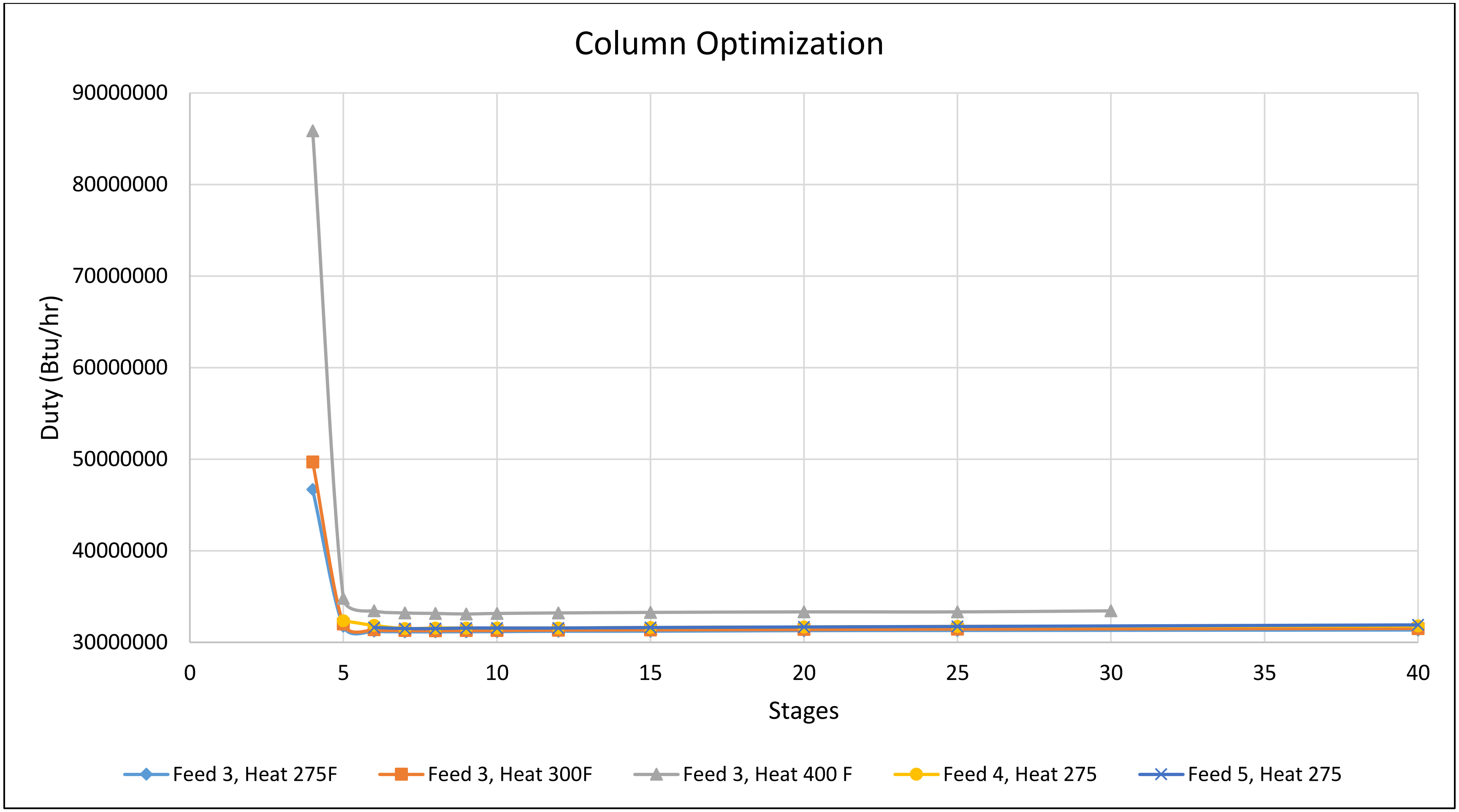


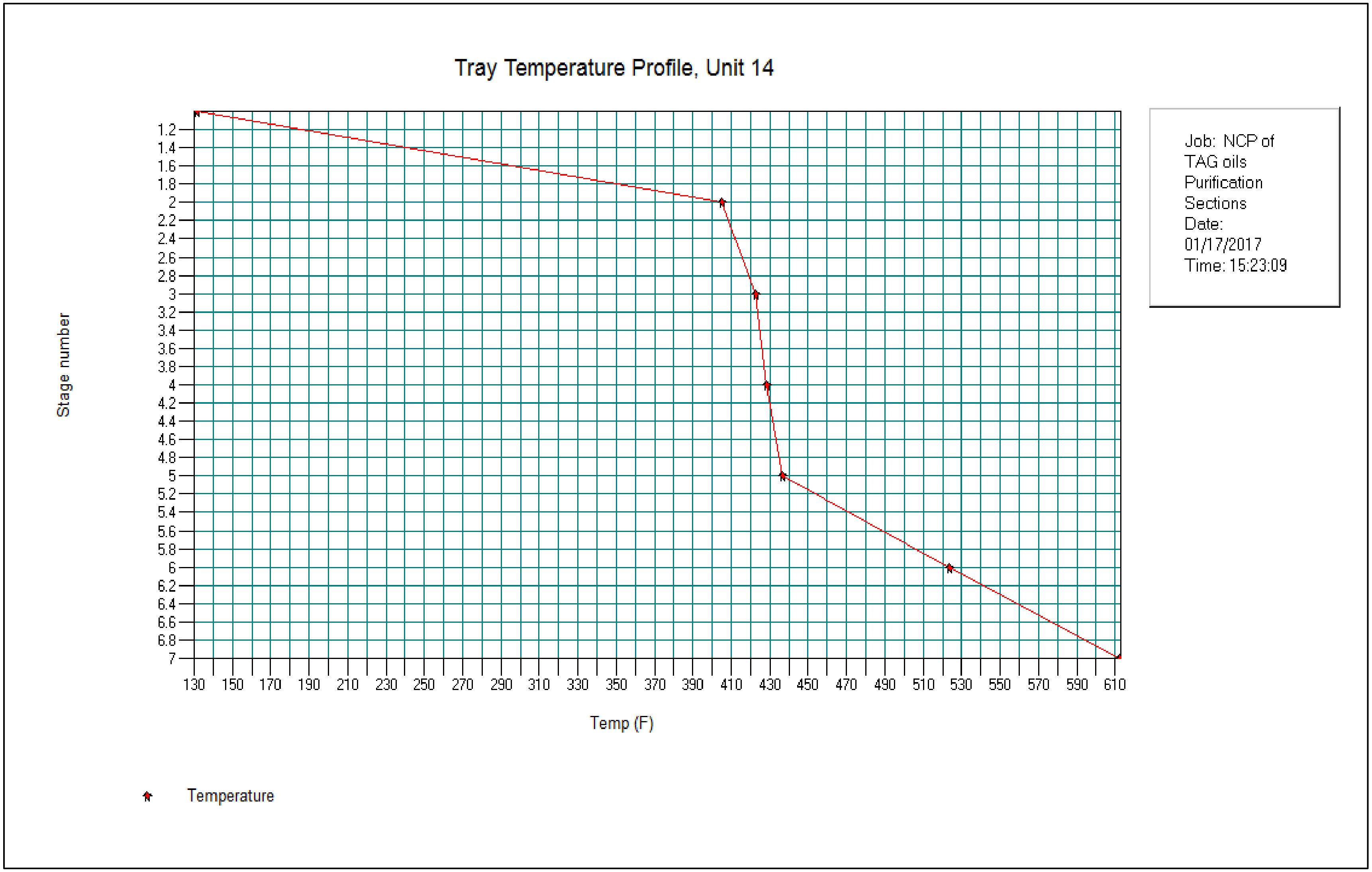

Column Optimization
19000000
17000000
15000000
13000000
11000000
9000000
7000000
5000000
3000000
1000000
Duty (Btu/hr)
20
25
30
35
40
45
50
Stages
Feed 13, No Heat/Cool
Feed 15, No Heat/Cool
Feed 17, No Heat/Cool
Feed 18, No Heat/Cool
Feed 17, Cool 450F
Feed 17, Cool 470
Feed 17, Cool 440F



Column temperature profile.

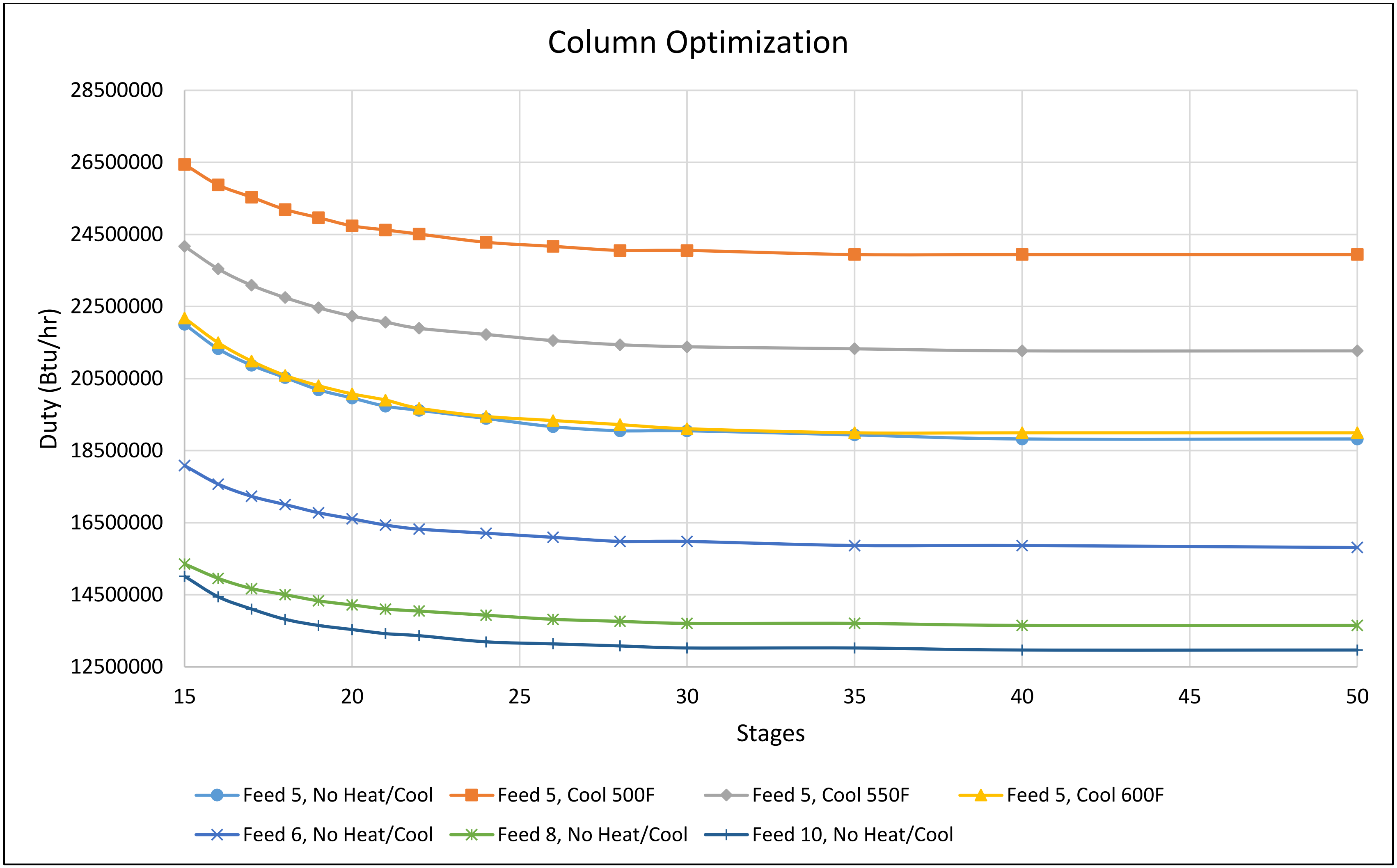
Atmospheric Column (D-701)

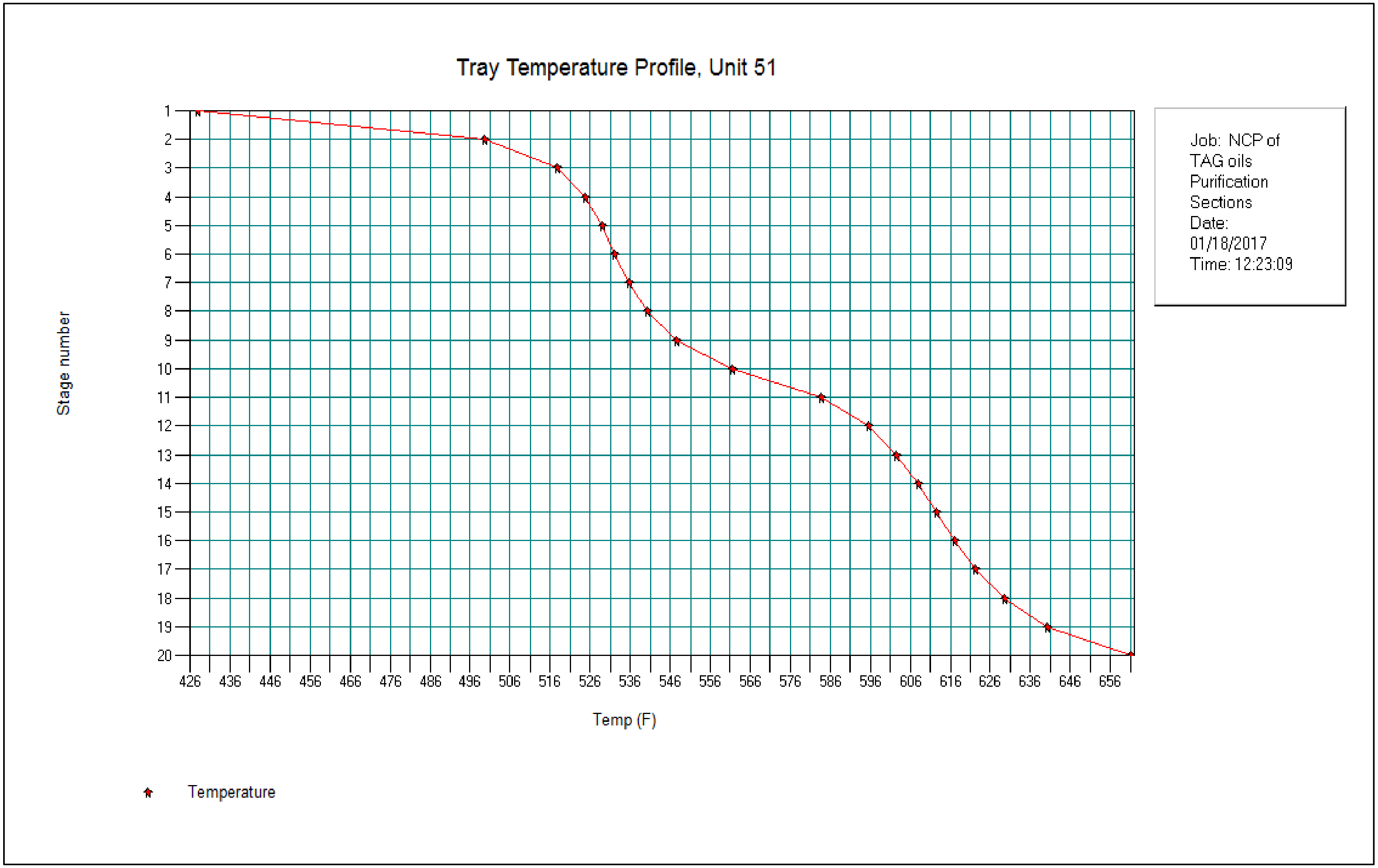




Column temperature profile.

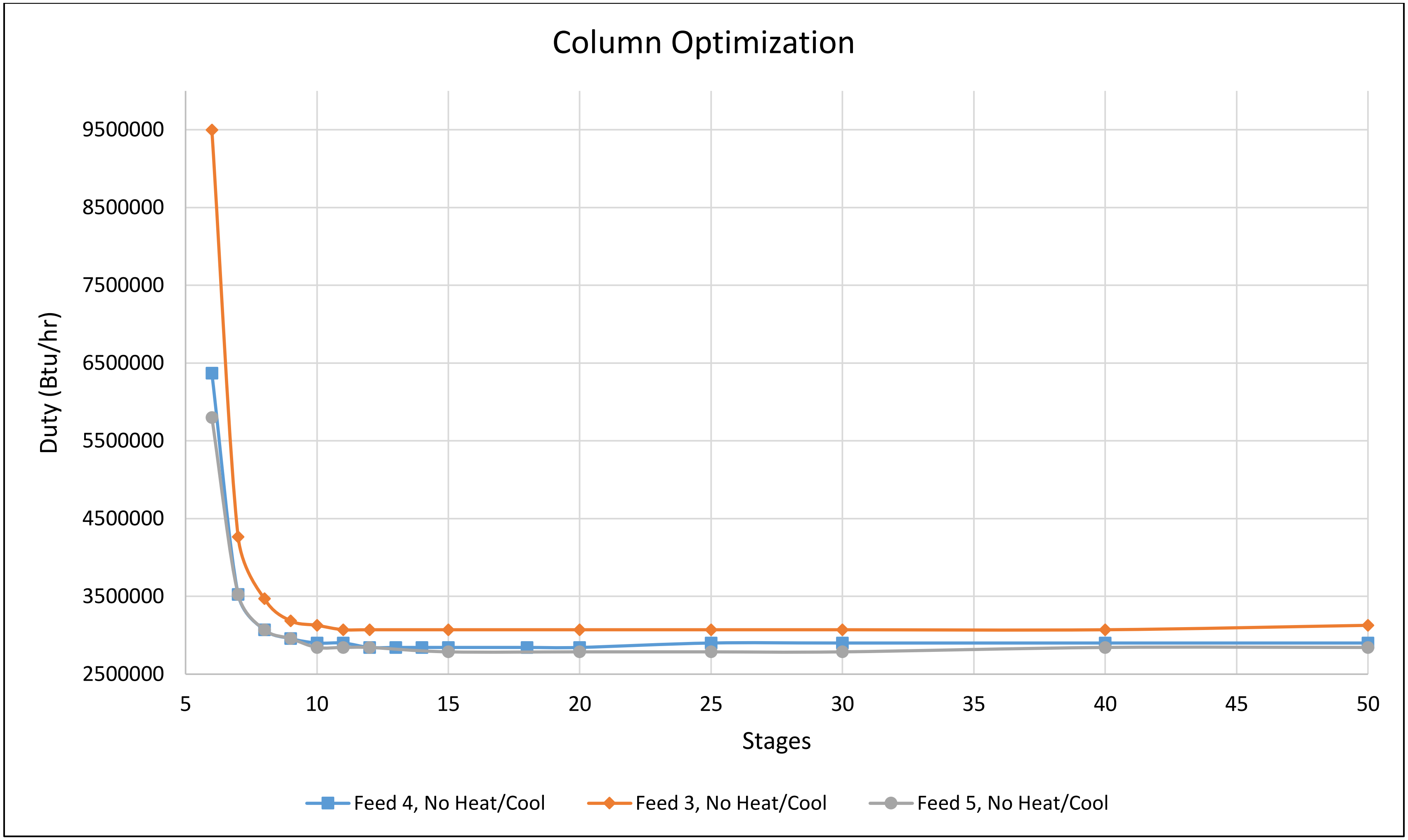
Vacuum Column (D-702)

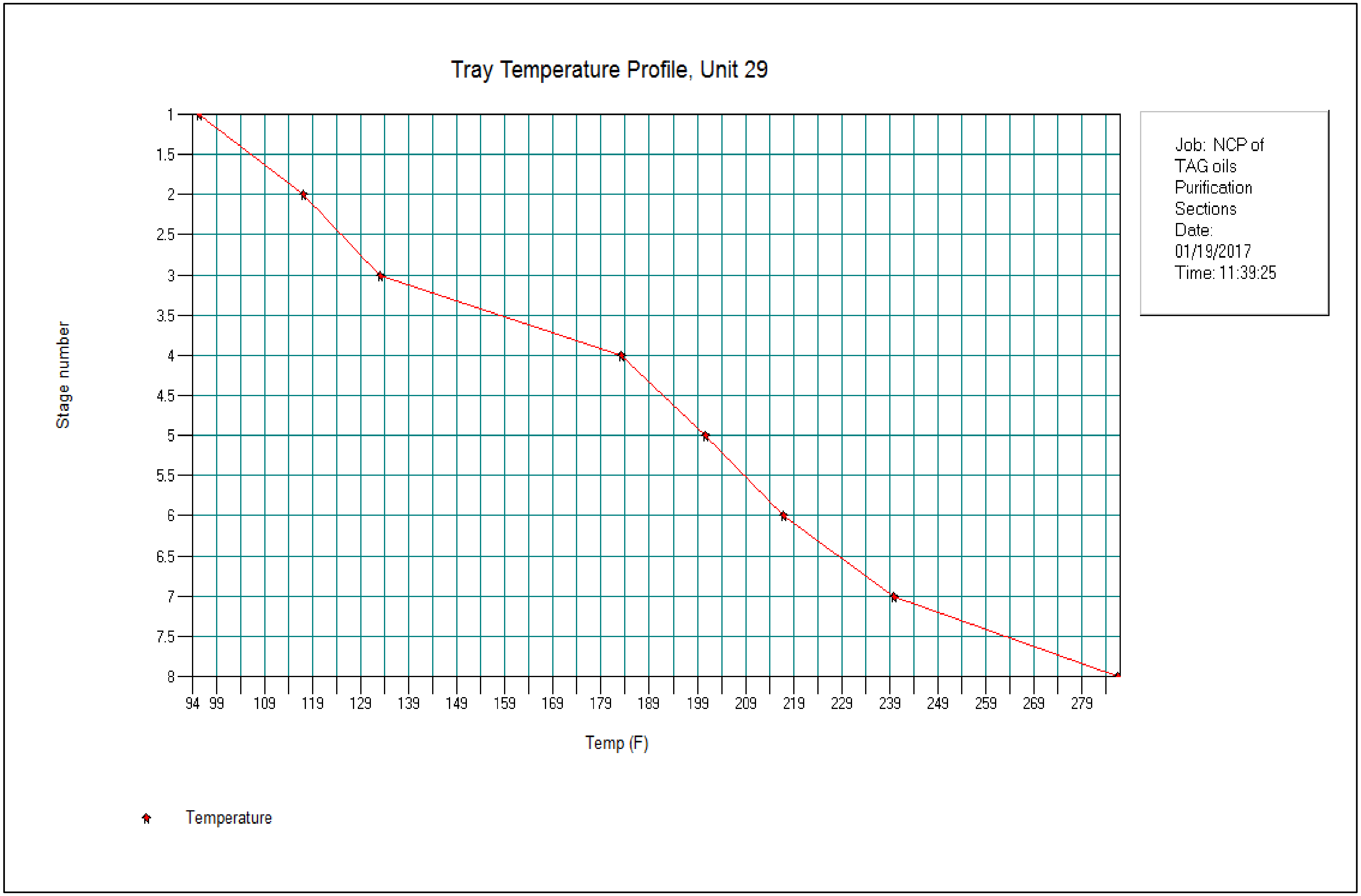




Column temperature profile.

Hexane Splitter Column (D-715)





Column temperature profile.

Appendix F. List of Assumptions

1. All ChemCad simulations are comparable to real life situations.
2. The thermodynamic model of SRK was used for the base design based on information from Separation Process Engineering, while the UNIFAC and NRTL models were used for the fatty acid extraction design [46].
3. The initial soybean oil feed was assumed to be 10% palmitic acid, 4% stearic acid, 12% linolenic acid, 51% linoleic acid, and 23% oleic acid. All percentages are based on mass percent.
4. All reactors found within the plant were designed based on the previous experimental work, as described in Chapter I of this thesis. In addition, the contents coming out of the fatty acid extractor, coker, and pitching reactor were all designed this way as well.
5. It was assumed all of the acetic acid, and 10% of the propionic acid are removed in the aqueous phase in the three phase flash drums. This information was based off of Ben Jones work, and needs to be revisited [39].
6. It was assumed that the heavy ends needed to stay in a temperature range of 150-350 °C so they would be viscous enough to flow while staying thermally stable.
7. It was assumed all transportation fuel product specs were met as long as the specifications capable of being measured by a simulator were within specification. This procedure was described in Chapter II.
8. All pieces of equipment were designed as described in Chapter II, including various height to diameter ratios, efficiencies, residence times/surge volumes, flooding fractions, vapor flows and flow rates, and pressure drops. Sample calculations of how each piece of equipment was sized can be found in Appendix D.

9. The TTCR was designed to be run as two reactors in parallel, and designed as a single shell and double tube heat exchanger. This is all based on work performed by Linnen et. al [10].
10. Flame temperature calculations were performed, as shown in Appendix D, and based on these calculations it was assumed the Syngas produced during the process could be burned hot enough to create all steam on site. The furnaces were then priced based on the required duties. This is an area that should be revisited to tighten up the ±40% economic analysis.
11. Varsol was priced based on information from Exon mobile.
12. All assumptions regarding how the economic analysis was performed can be found in Chapter II. Sample calculations can be found in Appendix D, and intermediate economic results can be found in Appendix C.
13. Assumed a hurdle rate of 12%
14. It was assumed that carbon steel could be used for a material of construction for all equipment not in contact with the fatty acids. If the equipment is in contact with acids then stainless steel must be used. Materials of construction of the scalable experimental equipment used in previous work were used for the process.
15. The most current economic indicator from Chemical Engineering was for April 2016, and will be used for all economic calculations [52].
16. The FCI was spread out of two years based on the longest lead time for quoted equipment. This was 42 weeks for the compressor, so the FCI was spread out over two years, running from year -1 to 0. This duration reflects the total time required for design, procurement, and installation.

17. A MACRS method over 15 years was used to calculate the depreciation of the FCI.
18. It was assumed that the amount of coke produced during the processing of the heavy ends would not be economical. Roughly ten plants worth of coke needs to be produced to have a delayed coking and calcination facility of typical world scale.
19. It was assumed that a 99% purity for all acids produced would be good enough for sale.
20. If not all the syngas needed to be burned it the boiler it was taken as a credit. This credit was found based on a typical natural gas heating value and price, and was discounted to the syngas heating value.
21. Income taxes were based on MN tax prices. This is because the plant was assumed to be built in close proximity to a soybean oil processing plant located in Wilmer, MN. This plant description can be found in Chapter XI.
22. The pitching reactor was priced based on information from Dr. Wayne Seames. It was designed as a scraped surface heat exchanger, and was priced at 600,000 € 7 years ago. This price was then adjusted to USD based on a conversion of 0.83404 USD/EUR from June of 2010.
23. Any leftover syngas produced during the process was sold at a discounted natural gas price for a heat credit.
24. The density of air at 150 °F and atmospheric pressure was assumed to be 0.15 lb/ft^3, and the heat capacity was assumed to be 0.242 Btu/lb°F [67].
25. It was assumed that the power requirement for the pitching reactor would be comparable to a ribbon mixer that is used in the polymers industry [66]. This power calculation can be found in Appendix D.

26. The screw conveyer used to collect the mesophase pitch out of the pitching reactor was designed to be uninsulated, so the pitch can return to ambient temperature slowly along the conveyor.
27. The price of the mesophase pitch was discounted 30% to take into account the processing of the pitch into the carbon fiber.
28. When removing unnecessary processing equipment from the soybean oil extraction facility the following unit operations were removed: Oil Stripper, Gummed Oil and Water Mixer, Degumming Reactor, Degumming Centrifuge, Oil Dryer, and four additional pumps.
29. Based on the previous assumption, the following utility requirements were removed: 277 hp worth of electricity, 14,000 lb/hr of 400 psia steam, and 4.9×10^5 Btu/min worth of natural gas.
30. Based on the removal of the equivalent of 5 major unit operations, 10% of the cost of the processing section of the plant was discounted when combining the broad cost estimates for the soybean oil extraction plant and base design with mesophase pitch recovery.

Appendix G. Equipment Quotes and Communications

G.1. CEPCI Economic Indicators

Amsley-Benzie, Shelby

Reply all|

Tue 6:02 PM

Dorothy Lozowski <DLozowski@accessintel.com>

Sent Items

Thank you very much.

-Shelby

DL

Dorothy Lozowski <DLozowski@accessintel.com>

|

Tue 5:58 PM

Untitled.pdf453 KB

Download

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Dear Shelby,

Attached you will find our most recent CEPCI numbers from our July issue. I hope this helps. Good luck with your project and your further studies.

Regards,

Dorothy Lozowski
Editor in Chief
Chemical Engineering
40 Wall Street
50th floor
New York, N.Y. 10005
(212)621-4678

AS

Amsley-Benzie, Shelby

|

Tue 4:44 PM

Good afternoon Dorothy,

My name is Shelby Amsley-Benzie and I am a graduate student at the University of North Dakota. I am currently working on a research project that involves designing a facility that can turn soybean oil into jet fuel. In order to accurately determine the price of this facility we are using the Chemical Engineering Process Design and Economics written by G.D. Ulrich. I am wondering if I could get the most recent CEPCI so that we may accurately price our equipment for the process.

Sincerely,

Shelby Amsley-Benzie
B.S ChE, Graduate Student
University of North Dakota,
shelby.amsleybenzie@ndus.edu
218-301-9466

G.2. Refrigeration Unit

Sandy Younger <sandymn25@gmail.com>

|

Tue 3:59 PM

J. C. Younger Company
Industrial chiller
5626 West Lake Street
Saint Louis Park, MN 55416
www.jcyounger.com

July 12, 2016

Dear Shelby,

Per your request:
I find your cooling load to be in the range of 4,000-6,000 tons at 50F LWT.
Due to the scale of this system required, I would have to direct you off to Krack for pricing, as wel as secondary re-run of numbers.
http://www.krack.com/en/process-cooling/Pages/default.aspx

Best of luck on this.

Sandy Younger
JC Younger Company Inc. “Your Chiller Pro’z”
www.jcyounger.com
My shop number is 952-929-1838 or my 24/7 cell phone number is 612-250-5397
ETL LISTED / USA MADE
Master Refrigeration Licensed Shop
Fully insured and bonded
Full JCY staff graduated by Dunwoody Technical College
Family owned and operated since 1956
Doing Business in MPLS area since 1956 “Helping support local industry”
Legal disclaimer:

AS

Amsley-Benzie, Shelby

Reply all|

Tue 3:48 PM

sandy@jcyounger.com

Sent Items

Sandy,

Just following up with our phone conversation. Thanks again for the help. If you need any more information let me know.

-Shelby

Amsley-Benzie, Shelby

|

Tue 5:29 PM

Thank you for the help!

-Shelby

JJ

Jeff Johnson <jeff@componentsalesmn.com>

|

Tue 5:04 PM

You will need to talk to www.zero-zone.com or www.multistack.com

They both build large chillers.

I represent www.krack.com who doesn't build chillers.

Jeff Johnson
Component Sales
23386 Grandview Trail

Lakeville, MN 55044
www.componentsalesmn.com
jeff@componentsalesmn.com
651-249-9961 Phone
866-729-9540 Fax

AS

Amsley-Benzie, Shelby

Reply all

Tue 4:52 PM

jeff@componentsalesmn.com

Sent Items

Jeff,

My name is Shelby Amsley-Benzie and I was working withSandy from JCYounger to get a rough budgetary estimate on a refrigeration unit. This unit is part of a process we are designing through the University of North Dakota. We are in the final stages, and are waiting on the final funding, but in order to receive the funding I need to put together a budgetary estimate. Due to the scale of the system, JCYounger directed me towards you for a price. The pricing I am looking for is just a budgetary estimation at a +/-40% level. Sandy found the unit to be in the cooling range of 4,000-6,000 tons at 50F LWT. The process needs to cool a solvent from 420F to 50F at 4000 lb/min at 480 volts power, 3 phase, air cooled system.
Any help on the subject would be greatly appreciated. If there are any questions feel free to contact me.

Sincerely,

Shelby Amsley-Benzie
B.S ChE, Graduate Student
University of North Dakota
shelby.amsleybenzie@ndus.edu
218-301-9466

TELEPHONE CONVERSATION RECORD

ORIGINATOR: Shelby Amsley-Benzie RECEIVER: Shane Eskelson

PHONE NUMBER: 218-301-9466 PHONE NUMBER: 701-235-0521

DATE OF CALL: 7/13/2016 TIME OF CALL: 2:30 pm

APPROX. DURATION: 10 min

REASON FOR THE CALL: I was trying to receive a price quote on a refrigeration unit.

Summarize the contents of the conversation below. Use exact quotations of important statements made by either party:

I explained to Shane that I am a graduate student working at UND, and I needed a rough budgetary estimate at the +/-40% level. I explained that I had previously been talking with and emailing Sandy Younger of JCYounger Company, and that he already sized out the system I would need. Also, Sandy forwarded me along to Multistack, and then Trane to get a pricing estimate due to the scale of the system I require. From there Shane explained he had been working with UND earlier this year pricing a cooling system, but UND didn't go through with the project due to the price. It was through the drafting department at UND. I told Shane that the required cooling load would be 4,000-6,000 tons at 50F LWT. From this he was able to give me a price right away. As he stated "I just recently priced a 2000 ton load, so I know that the range you are looking for would be about $4.5 million." From there I thanked him for his help, and he said if I need anything in the future feel free to call. He is a representative of Trane in Fargo, ND. He also ended my recommending I look at TMI Climate Solutions for a picture of the type of system I would get for this price. It includes everything (pipes, pumps, cooling tower, etc.)

RECORDED BY: Shelby Amsley-Benzie DATE: 7/14/2016

G.3. Fired Heater

Justin Forth <Justin.Forth@TulsaHeatersMidstream.com>

|

Today 2:42 PM

Shelby,

Typical delivery time is 26-30 weeks depending on scope, shop capacity at the time of order, and customer needs. If something faster is needed, we can evaluate at or near the time of order to get the best possible delivery.

Let me know if you need anything else.

Thanks,

Justin

AS

Amsley-Benzie, Shelby

Reply all

Today 1:25 PM

Justin Forth <Justin.Forth@TulsaHeatersMidstream.com>

Sent Items

Justin,

Thank you very much for getting back to me so quickly. This should be all I need at this point for a price. I was wondering if you had an estimated time for procurement for basic scheduling purposes. Again this just needs to be a rough estimate at this time.

Thank you again for the help,
Shelby Amsley-Benzie

Amsley-Benzie, Shelby

Today 1:25 PM

Justin,

Thank you very much for getting back to me so quickly. This should be all I need at this point for a price. I was wondering if you had an estimated time for procurement for basic scheduling purposes. Again this just needs to be a rough estimate at this time.

Thank you again for the help,
Shelby Amsley-Benzie

JF

Justin Forth <Justin.Forth@TulsaHeatersMidstream.com>

|

Wed 3:58 PM

Tulsa Heaters Midstream - SHO Heater Brochure.pdf3 MB

Download

Save to OneDrive - North Dakota University System

Shelby,

Thanks for the email. Your request was passed along to me at Tulsa Heaters Midstream, a sister company of THI. We specialize in packaged heaters that are skid mounted for ease of delivery and installation. We believe that it will be a better solution for your type of application.

For +/- 40%, a budget figure would be $550,000. There are quite a few things we could do to minimize this cost depending on how you would like the system configured, what other equipment/buildings will be located around the heater, etc. This cost includes the heater itself, the burner, blower, and fuel and air controls for the system. I have attached one of our brochures so that you can see the type of system we typically supply.

We can work on a more detailed design and provide a formal proposal if that is required at some point. Let me know if you need anything else.

Thanks,

Justin Forth | *Sr. Applications Engineer*
Tulsa Heaters Midstream
Cell: (918) 497-8721
www.tulsaheatersmidstream.com | LinkedIn | Facebook

From: Amsley-Benzie, Shelby [mailto:shelby.amsleybenzie@und.edu]
Sent: Tuesday, July 12, 2016 2:37 PM
To: rfq@tulsaheaters.com
Subject: Fired Heater Quote

I am currently working on research through the University of North Dakota, and we are trying to get funding to further develop the technology we have that allows us to produce drop in ready jet fuel from soybean oil. In order to get further funding for higher level development (currently at the preliminary/scoping study phase of design), I need to put together an economic assessment. I am only looking for a budgetary estimate at the +/-40% level.

I am inquiring about a quote for a fired heater. The heater would require a duty of 412000 BTU/min, and 4 tube banks. We will be burning an on site natural gas stream as our fuel source. If there is any other information you need please feel free to contact me. Any help on the subject would be greatly appreciated.

-Thank you,
Shelby Amsley-Benzie

AS

Amsley-Benzie, Shelby

Reply all

Tue 2:37 PM

rfq@tulsaheaters.com

Sent Items

I am currently working on research through the University of North Dakota, and we are trying to get funding to further develop the technology we have that allows us to produce drop in ready jet fuel from soybean oil. In order to get further funding for higher level development (currently at the preliminary/scoping study phase of design), I need to put together an economic assessment. I am only looking for a budgetary estimate at the +/-40% level.

I am inquiring about a quote for a fired heater. The heater would require a duty of 412000 BTU/min, and 4 tube banks. We will be burning an on site natural gas stream as our fuel source. If there is any other information you need please feel free to contact me. Any help on the subject would be greatly appreciated.

-Thank you,
Shelby Amsley-Benzie

G.4. VM&P Naphtha

Samuel Arneson/Great Lakes/Brenntag <SArneson@brenntag.com>

Reply all|

Today 3:49 PM

Amsley-Benzie, Shelby

H0371128.pdf42 KBCredit Application.doc538 KB

2 attachments (580 KB) Download all

Save all to OneDrive - North Dakota University System

Action Items

Hi Shelby,

Attached you will find a Brenntag credit application, as well as Certificate of Analysis for VM&P Naptha.

The credit app will allow us to set you up with a Brenntag account.
Please sign the COA and scan it back to me. For safety reasons, Brenntag requires customers to verify the material before all first-time deliveries.

Please feel free to call if you have any questions.

Thanks,
Sam Arneson
Brenntag Great Lakes
262-853-4193

AS

Amsley-Benzie, Shelby

|

Today 1:37 PM

Just following up with our phone conversation from yesterday. I am working for the University of North Dakota and was inquiring about your VM&P naphtha prices. Once I talk to the person in charge of the project I will get back to you.

Thanks for the help,
Shelby Amsley-Benzie

TELEPHONE CONVERSATION RECORD

ORIGINATOR: Shelby Amsley-Benzie RECEIVER: Samuel Arneson

PHONE NUMBER: 218-301-9466 PHONE NUMBER: 262-853-4193

DATE OF CALL: 7/13/2016 TIME OF CALL: 2:15 pm

APPROX. DURATION: 5 min

REASON FOR THE CALL: Price on VM & P Naphtha

Summarize the contents of the conversation below. Use exact quotations of important statements made by either party:

We talked about getting a basic buying price of the Naphtha for budgetary purposes at the University. He said, "Bulk orders are discounted to $1.03." I replied that this would be the price we would be looking at. He also mentioned that in order to be competitive they would be able to drop the price lower depending on competitor prices. We also followed up with email correspondence.

RECORDED BY: Shelby Amsley-Benzie DATE: 7/14/2016

G.5. Distillation Trays

Sieve Tray Cost Estimate

AS

Amsley-Benzie, Shelby

|

Today 1:03 PM

Kris,

Yes that is all I needed.

Thank you for the help,

Shelby

FK

Flaska, Kris <Kris.Flaska@KochGlitsch.com>

|

Today 11:55 AM

Shelby

Normal delivery is about 16 weeks from date of order. Is this what you need?

Kris Flaska

Regional Manager
Koch-Glitsch
9891 Montgomery Road
Suite 246
Cincinnati, Ohio 45242
Office : 513-720-5624
Fax: 316-828-9908
Cell: 513-290-2623
[kris.flaska@kochglitsch.com]kris.flaska@kochglitsch.com
[www.koch-glitsch.com]www.koch-glitsch.com

From: Amsley-Benzie, Shelby [mailto:shelby.amsleybenzie@und.edu]
Sent: Monday, July 18, 2016 9:23 AM
To: Flaska, Kris
Subject: Re: Sieve Tray Cost Estimate

Sent by an external sender. Use caution opening attachments, clicking web links, or replying unless you have verified this email is legitimate.

AS

Amsley-Benzie, Shelby

|

Today 8:22 AM

Kris,
Thank you very much for getting back to me so quickly. The only other question I have is what would be the procurement time on those trays.

Thank you,
Shelby

FK

Flaska, Kris <Kris.Flaska@KochGlitsch.com>

|

Sat 7/16

Shelby

Thanks for the note. I am not sure what the application for the tower service but assumed tray efficiency of 65%, so actual # of trays would be 60. I also assumed 2 –pass trays since the tower is 9.2 I.D.   Budget price (+/- 10%) is $165,000.

Please let me if there is anything else you need.

Sincerely

Kris Flaska

Regional Manager
Koch-Glitsch
9891 Montgomery Road
Suite 246
Cincinnati, Ohio 45242
Office : 513-720-5624
Fax: 316-828-9908
Cell: 513-290-2623
[kris.flaska@kochglitsch.com]kris.flaska@kochglitsch.com
[www.koch-glitsch.com]www.koch-glitsch.com

From: Amsley-Benzie, Shelby [mailto:shelby.amsleybenzie@und.edu]
Sent: Thursday, July 14, 2016 6:10 PM
To: Flaska, Kris
Subject: Sieve Tray Cost Estimate

Sent by an external sender. Use caution opening attachments, clicking web links, or replying unless you have verified this email is legitimate.

AS

Amsley-Benzie, Shelby

Reply all|

Thu 7/14

Kris.Flaska@KochGlitsch.com
Sent Items
Kris,

I am currently working on some research through the University of North Dakota, and I am looking for a rough budgetary estimate of sieve trays. I worked with you and Koch a few years ago during my undergrad, and you were able to help us out back then. I am just looking for a rough estimate at the +/-40% level for a column with a height of 123 ft and diameter of 9.2 ft. Through my simulation there would be 40 theoretical stages, with trays spaced 24 inches. I am looking for a price in carbon steel.
Any help on the subjected would be greatly appreciated, thank you for your time.
Sincerely,
Shelby Amsley-Benzie
shelby.amsleybenzie@ndus.edu
218-301-9466

G.6. 3 Stage Compressor

Budgetary Estimate for 3 Stage Compressor

AS

Amsley-Benzie, Shelby

|
Mon 3:21 PM
Thank you for the help.
-Shelby

BP

Bezdicek, Paul <paul.bezdicek@irco.com>

|
Mon 3:12 PM
Use $2.5M, lead time 38-42 Week Lead Time

BP

Bezdicek, Paul <paul.bezdicek@irco.com>

Reply all|

Mon 2:53 PM

Amsley-Benzie, Shelby

That will work, we need the elevation for running some of the preliminary calcs.

Paul

AS

Amsley-Benzie, Shelby

|

Mon 2:52 PM

At this stage we are just looking for a budgetary estimate until further funding comes in on the project. In order to get the funding we need an idea of the price. Therefore, I guess we could say the customer as of now would be UND, but we would be looking for it to be delivered to Wimer, MN.

Thanks for the quick response.

-Shelby

BP

Bezdicek, Paul <paul.bezdicek@irco.com>

|

Mon 2:22 PM

Who is the customer and where is it going geographically?

Let me do some work,

Paul Bezdicek
Senior Sales Engineer
Ingersoll Rand Industrial Technologies
Sioux Falls, SD

Office +1.402.330.5831
Mobile +1.605-809-6299
Fax +1.402.330.1271
Email: paul_bezdicek@irco.com
Website: www.ingersollrand.com

Paul

AS

Amsley-Benzie, Shelby

Mon 1:54 PM

Paul,

I am currently working on research through the University of North Dakota. I know you have been helpful in the past with helping some of the senior students to get quotes for equipment for their senior design class. I was hoping you could help me out with a price on a 3 stage compressor I am designing.

I am looking for a rough budgetary estimate (+/-40%) for a three stage compressor with a flow of 640 lb/min of light hydrocarbon gases. These light hydrocarbons include C6 and lighter, as well as CO_2 and CO. The suction pressure is 15 psia, and the discharge pressure is 460 psia. The process simulator used to design it (ChemCAD) said the unit would require a total power of 3150 hp at 55% efficiency. Also, an idea of the procurement time for the compressor would be beneficial.

As I said before, only a rough budgetary estimate is needed, and any help on the subject would be greatly appreciated.

Sincerely,
Shelby Amsley-Benzie
BS ChE, Graduate Student, University of North Dakota
shelby.amsleybenzie@ndus.edu

G.7. Nitrogen Quote

Gas Cost Estimator

BJ

Bornhorst,Bradley J. <BORNHOBJ@airproducts.com>

Reply all

Mon 2:27 PM

Amsley-Benzie, Shelby

Hi Shelby,

Thank you for reaching out to Air Products. We would be happy to assist you in a cost estimate for a bulk Nitrogen supply. What I can do is refer you to our website where you can find a page that provides this tool. The url is: www.airproducts.com/gce This page will ask you to register a free account and then answer a couple questions based on your requirements. After you submit you should receive a rough estimate that can be used in your budgetary project.

Any further questions, please feel free to reach out.

Thank you,

Bradley Bornhorst
Lead Specialist
Air Products and Chemicals, Inc
(800) 878-5973 ext 20046
www.airproducts.com

Gas Cost Estimator

Based on the information you supplied:

Delivery Location Zip Code:

56201

Product:

Nitrogen

Monthly Volume (SCF):

63,380

Usage:

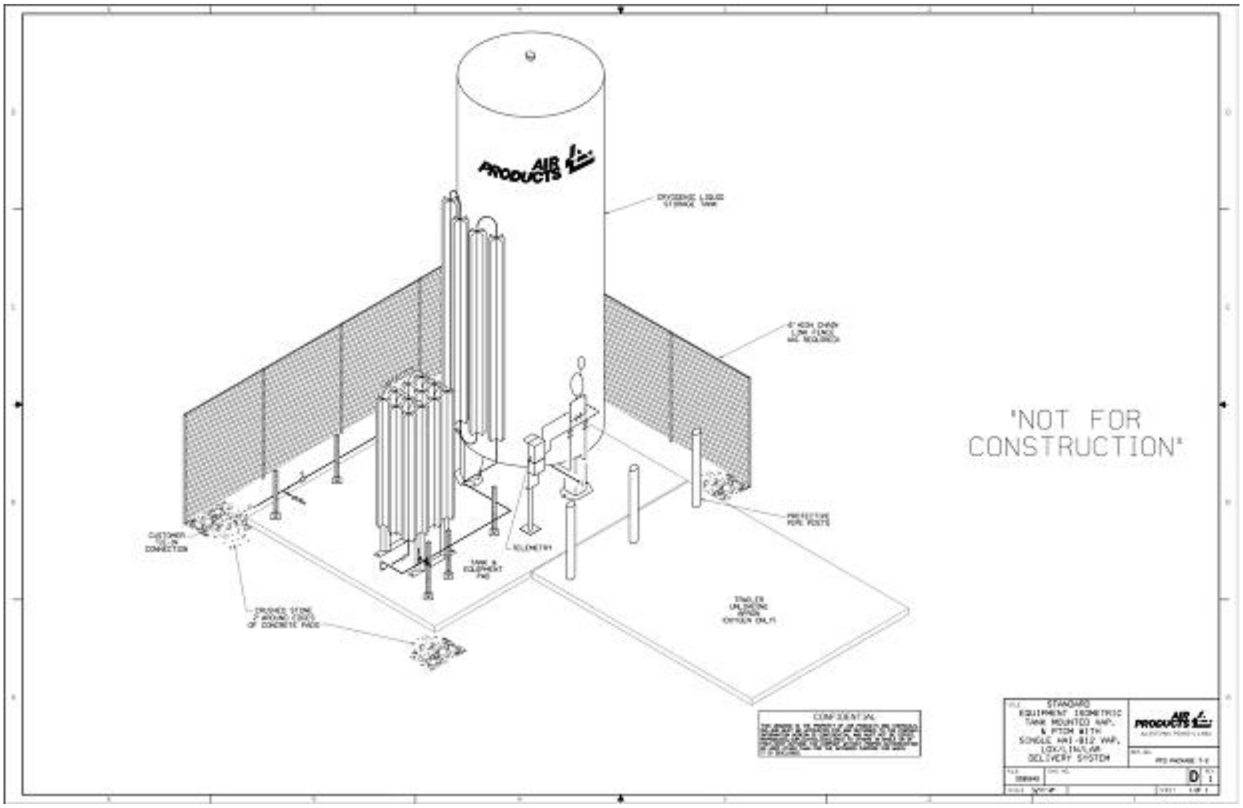
Gas Only

and the following assumptions

- Air Products owns the equipment
- 24 hrs/day, 7 days/week operations
- 24/7 delivery access
- Standard pressure
- Standard purity

Gas Cost Estimate Disclaimer

Product Supply Information



Hover over areas of the image above to view a description of the tank, vaporizer, and pad.

Projected monthly cost: $9,806 - $13,630
Nothing contained in this site shall constitute an offer by Air Products to sell products or services. Due to the limited information supplied this should not be construed as a final price offer, but as an estimate. Contact us at 1-800-654-4567 for a formalized price quote.

Proposed Supply System:
500 Gallon, Nitrogen, Gaseous, Side Arm and VAI - 806 Vaporizers
3-D Equipment Layout
Equipment Layout
Nearest Air Products Supply Point:

- Oak Creek, WI
- LaSalle, IL

Reference Information:
Gaseous Safetygram
Liquid Safetygram
MSDS

Change Product Requirements | Save Estimate

G.8. Varsol Quote

Paula Slavin <Paula.Slavin@univarusa.com>

Reply all|

Fri 2:27 PM

Amsley-Benzie, Shelby

Hi Shelby,

We have been trying to source this material for you, but unfortunately, we will not be able to provide it. The material is a blend and therefore has to be made in batches of several drums at a time. We do not have any other demand for it.

Sorry that we will not be able to help with this.

Best regards,

Paula Slavin
Account Representative
Univar
T +1 866 647 0132

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Take our one-minute survey and tell us how we're doing

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G.9. Delayed Coking Unit

Kimbrell, Michael R <michael.kimbrell@bp.com>

|

Fri 6:01 PM

Shelby,

Thanks for your e-mail. A unit of this very small size would be difficult for me to estimate. A guideline cost for a Delayed Coker that does not include site preparation, utilities like air, sewer, firewater, power or flare is $7500 per each barrel per day of unit capacity. Your unit is roughly a 2000 barrel per day unit. With that metric, the cost of the unit alone would be $15 MM. That guideline works for units that are 20,000 BPD and up. I would think the smaller size unit would be less than this value.

A moderately sized 2-drum Delayed Coker will have a capacity of between 15,000 and 20,000 BPD feed. The unit size you are contemplating is much smaller than a traditional commercial unit and much larger than a lab scale unit. Everything on it would be custom, so the costs would be high for the unit size, but the amount of metal and size of valves will be low for the unit so I am not clear on how to estimate the costs.

If you were willing to pay a licensor for a cost estimate; Amec Foster Wheeler, Bechtel Hydrocarbon Technology Solutions, CB&I are the three licensors of Delayed Cokers and they would be able to provide you an estimate. Some of the Engineering, Procurement, Construction (EPC) companies like Fluor or Jacobs could provide an estimate as well, but they will likely need to bill you for it.

Sorry that I am not much more help.

Mike

AS

Amsley-Benzie, Shelby

Reply all

Thu 1:11 PM

michael.kimbrell@bp.com

Sent Items

Michael,

I am currently a graduate student at the University of North Dakota. We are working on developing a process that is capable of producing drop in ready jet fuel and diesel fuel from soybean oil. In addition to the fuels we can produce anode grade coke as a byproduct. We are in the final stages of development, and are waiting on further funding to implement the process at the world scale. In order to get further funding, an economic assessment surrounding the process must be performed. For this assessment I need a rough budgetary estimate surrounding the delayed coking system we would need for the process.

The system would need to be able to process 620 lb/min of vacuum bottoms coming off of our vacuum column. I was hoping you could help me out with a rough budgetary estimate. At this stage we only need a rough estimate at a +/-40% level. If you aren't able to help, could you possibly point me in the direction of someone who could? Thank you for your time, and any help on the subject would be greatly appreciated.

Sincerely,
Shelby Amsley-Benzie
Graduate Student, University of North Dakota
shelby.amsleybenzie@ndus.edu
218-301-9466

G.10. Coke Calcination Unit

Coke Calcining System University of North Dakota feed 75 lb/min of green coke

AS

Amsley-Benzie, Shelby

|

Today 1:00 PM

Thank you for the help!
-Shelby

RS

Roland K. Seward <roland.seward@metso.com>

|

Today 6:37 AM

Month 0 - Order release
Month 6 – mobilize at site, clearing and begin foundation work
Month 10 to 14 – equipment delivery
Month 18 – mechanical completion
Month 19 – refractory dry out, testing and commissioning

Best regards

Roland Seward, PE
Manager, Capital Equipment Proposals

Metso

350 Railroad Street, Danville PA, 17821 USA

Mobile: +1 570 317 3562
Phone: +1 570 271 7668

Roland.Seward@metso.com
www.metso.com

Connect with us

AS

Amsley-Benzie, Shelby

|
Mon 6:42 PM

Roland,

Thank you for the quick response. Do you have a rough idea of the amount of time for procurement for the equipment?

Thanks again for all the help.

-Shelby

RS

Roland K. Seward <roland.seward@metso.com>

Reply all|
Mon 1:41 PM

Amsley-Benzie, Shelby;
John N. O'Malley <john.n.omalley@metso.com>;
Tom Lippencott <tom.lippencott@metso.com>

Action Items

Shelby

This reply is in response to and e-mail you sent to John O'Malley regarding a coke calcining process.

I would like to offer the following comments to help with your project.

Coke calciners are generally evaluated on ton per year, calcined coke basis, generally 24 hours per day, 330 days per year.

Assuming a green feed to product yield of 76%, 75 lbs per minute equals 13,500 tons per year, calcined coke basis and 150 lb/min equals 27,000 tons per year

Today, in general, modern plants require a size greater than 200,000 tons per year to be economical. However there are areas of the world that install smaller plants in the 100,000 tpy range. 13,500 to 27,000 is small capacity and may be difficult to justify economically.

Estimated costs are as follows

	Equipment USD	Installation USD	Total USD
13,500 tpy (short tons)	10,800,000	6,500,000	17,300,000
27,000 tpy (short tons)	15,300,000	9,200,000	24,500,000

Included in the equipment cost

- Feed Bin
- Weight Feeder
- Airlock
- Kiln feed hood
- Firing system
- Transfer Chute
- Cooler
- Cooler discharge hood
- Cooler Dust Collector
- Afterburner - Secondary Combustion Chamber
- Waste Heat recovery boiler
- Exhaust gas cleanings system with sulfur removal
- ID Fan
- Stack
- Motors, motor starters, ACVF speed controllers, switch gear and transformers
- Instrumentation and Control System
- Refractory
- Structural Steel

Included in Construction costs

- Foundations
- Mechanical installation
- Electrical installation, wire, conduit, cable, wire tray and etc.
- Refractory installation

Not included

- Utilities brought to interface
- Roads, paving

- □□□□□□□□□Rail track
- □□□□□□□□□Buildings (office, warehouse and etc.)
- □□□□□□□□□Land

Fuel required to operate the plant – approximately 1 million Btu per ton of product

Electricity required to operate the plant approximately 40 kW/ton of product

Pricing and utilities are offered to indicate the magnitude of investment only and are not a binding offer to sell.

Good luck with project

Best regards

Roland Seward, PE
Manager, Capital Equipment Proposals

Metso
350 Railroad Street, Danville PA, 17821 USA

Mobile: +1 570 317 3562
Phone: +1 570 271 7668

Roland.Seward@metso.com
www.metso.com

Connect with us

From: John N. O'Malley
Sent: Friday, July 22, 2016 1:18 PM
To: Roland K. Seward <roland.seward@metso.com>
Subject: FW: Coke Calcining System University of North Dakota feed 75 lb/min of green coke

Hi Rol,

FYI

Regards,

John

From: Amsley-Benzie, Shelby [mailto:shelby.amsleybenzie@und.edu]
Sent: Friday, July 22, 2016 1:14 PM
To: John N. O'Malley <john.n.omalley@metso.com>
Subject: Coke Calcining System

John,

I am currently a graduate student at the University of North Dakota. We are working on developing a process that is capable of producing drop in ready jet fuel and diesel fuel from soybean oil. In addition to the fuels we can produce anode grade coke as a byproduct. We are in the final stages of development, and are waiting on further funding to implement the process at the world scale. In order to get further funding, an economic assessment surrounding the process must be performed. As soon as this funding is granted you would be our first call for the calcining system. For this assessment I need a rough budgetary estimate surrounding the calcining system we would need for the process.

Currently we would need a system that can process 75 lb/min of green coke. I was able to play around with a few numbers, and we would be able to increase our incoming feed up to 150 lb/min. I'm not sure if that could help make the calcining process more feasible. The estimate just needs to be at a +/-40% level. I really do need a rough estimate, so even if you could give me an idea of the price at +/-40% of a larger system I could scale it down to the desired size. Any help on the subject would be greatly appreciated.

Thank you,
Shelby Amsley-Benzie
Graduate Student, University of North Dakota
shelby.amsleybenzie@ndus.edu
218-301-9466

G.11. Decarboxylation Reactors

Request for Budgetary Estimate Price

WW

Wayne Whaley <waynew@arrowtank.com>

|

Fri 7/22

I'm still waiting for pricing from our head vendors. I hope to hear from them by next Tuesday.

Wayne Whaley, P.E.
Estimating Manager
Arrow Tank & Engineering

(763) 552-8238 direct line

AS

Amsley-Benzie, Shelby

Reply all|

Fri 7/22

Wayne Whaley <waynew@arrowtank.com>

Sent Items

Wayne,

Just checking in to see if everything with the cost estimation is going well. As I said before at this stage we only need a rough estimate at the +/-40% level, so please do not spend too much time working on it. Hope to hear from you soon.

Thank you,
Shelby Amsley-Benzie

AS

Amsley-Benzie, Shelby

|

Mon 7/18

Wayne,
Just an average size nozzle should be fine for this stage of cost estimation. Also, 405 psig is correct.

As for the reactor internals, at this point this is what we could come up with. If this is still not what you were looking for then can you just go a head and price it without the externals included. The internals of the reactor on the lab scale were stainless steel tube filled with 100 micron frits and glass wool. At of now this is all we will be able to provide. If this is not enough information then a price without the internals will have to do.

Thank you so much for your time.

-Shelby

WW

Wayne Whaley <waynew@arrowtank.com>

|

7/15/2016

Shelby-

We need more information about the internals or we'll have to exclude them from our bid. Knowing the size of the catalyst doesn't help as the reactor bed is part of the process design, which we don't do.

Do you have an idea of the sizes of the nozzles? Just an average size would do as I'm not sure if you're thinking of small (2") or large (12") nozzles.

Also, the design pressure is usually specified as psig. I just want to make sure that we get this right – the 420psia specified would be 405psig, correct?

Wayne Whaley, P.E.
Estimating Manager
Arrow Tank & Engineering
(763) 552-8238 direct line

AS

Amsley-Benzie, Shelby

|

7/15/2016

Bill,

Sorry for the lack of information prior. As I stated before the reactor I would need would operate at 600F and 420 psia. It would need to be made of either grade 304 or 316 stainless steel. The dimensions would be a diameter of 12.5 ft and a length of 73 ft. There would need to be 2 man ways and 7 additional nozzles. As for the internals it will be a fixed bed reactor. The catalyst particle sizes are 6 mm in diameter and 5 mm long. I hope this is enough information to get a rough budgetary estimate. Please let me know if there are any questions.

Thank you for your time,
Shelby Amsley-Benzie

BR

Bill Rice <bill@arrowtank.com>

|

7/15/2016

Shelby

Unfortunately, we do not have process design capabilities. We would need an approximate diameter and straight side length , material of construction and listing of required nozzles / manways and internals.

Regards,
Bill Rice

Sales
Arrow Tank & Engineering Co.
763-552-8226

From: Dave Haskins
Sent: Friday, July 15, 2016 9:34 AM
To: Bill Rice
Subject: Fwd: Request for Budgetary Estimate Price

Bill
Iwould try to work with this person
See below

Sent from my Verizon, Samsung Galaxy smartphone

AS

Amsley-Benzie, Shelby

|
7/14/2016

Dave,
I am currently working on research through the University of North Dakota, and we are trying to get funding to further develop the technology we have that allows us to produce drop in ready jet fuel from soybean oil. In order to get further funding for higher level development (currently at the preliminary/scoping study phase of design), I need to put together an economic assessment. I am only looking for a budgetary estimate at the +/-40% level.

I was wondering if your company would be able to price a specialty reactor where we catalytically deoxygenate acids present in a hydrocarbon steam. I am looking just for a rough price on the PBR we would need to get to accomplish this. The specs are as follows:

It would be a PBR reactor that operates at 600F and 420 psia. The total volume of catalyst in the bed would be 16922 ft3. This reactor would need to be built from 304 or 316 stainless steel.

As I said before I only need a rough budgetary estimate. Any help on the subject would be greatly appreciated, and once the funding comes through you would be our first call for further development of the process. If you have any questions please feel free to contact me.

Thank you,
Shelby Amsley-Benzie
BS ChE, Graduate Student
University of North Dakota
shelby.amsleybenzie@ndus.edu
218-301-9466

G.12. TTCR Reactor

TELEPHONE CONVERSATION RECORD

ORIGINATOR: Alllen Sheppard RECEIVER: Shelby Amsley-Benzie
PHONE NUMBER: 7152072163 PHONE NUMBER: 218-301-9466
DATE OF CALL: 7-28-2016 TIME OF CALL: 2:50 pm
APPROX. DURATION: 15 min
REASON FOR THE CALL: We had been in communication over the past two weeks, and he was working on getting a price quote for the TTCR. This call was to sort out the actual price quote.
Summarize the contents of the conversation below. Use exact quotations of important statements made by either party:

Allen walked me through how he calculated the price estimate for the TTCR. We reviewed the specs for the reactor. These include that we require 10,000 tubes at 80 ft in length. The reactor will be a U-shaped reactor, and the tubes need to be made of Inconel material of construction. The shell of the reactor will be built of 316 stainless steel. First, we went over that the cost of just that much tube footage in such a high quality metal will cost roughly $3.4 million, because it is priced out as roughly $4/foot. He also estimated the cost of the remaining part of the reactor by basing it off of a previous product they just produced and sold. The product they made cost roughly $200,000, and in order to have the required surface area for my project this would require roughly 50 of those units.

From there that resulted in a price of roughly $24 million. The actual estimate price needed to be bumped up because the construction of this vessel would be costly. This is because in order to handle the high temperatures and pressures that it will be exposed to a 1" shell would need to be constructed. This requires a lot more labor, which results in a higher price. This is how he came to the estimate of $30 million for the TTCR reactor. He also explained that this vessel would be almost impossible to transport, so he would recommend making smaller vessels and running them in parallel if this design was to actually be made.

RECORDED BY: Shelby Amsley-Benzie DATE: 7-29-2016

G.13. Catalyst Quotes

George Choong <George.Choong@matthey.com>

|

Today 2:05 PM

Quotation Univesity of North Dakota Pricat NI 55-5 T Aug 2 2016-signed.pdf126 KB JMI Standard Terms.pdf176 KB

2 attachments (303 KB) Download all
Save all to OneDrive - North Dakota University System

Dear Shelby,

Please find attached our quotation for 27,000 ft3 of the Pricat Ni 55/5 T 6x5 catalyst for your reference.

Regards,

George C. Choong
Technical Sales Manager - Chemicals
Johnson Matthey Inc.
2 Transam Plaza Drive #230
Oakbrook Terrace, IL 60181

Tel: (630) 268-6329
Fax: (630) 268-9797
Cell: (630) 248-9056
george.choong@matthey.com
www.jmprotech.com

BF

Bob Fair <Bob.Fair@jmusa.com>

Reply all|

Fri 7/29

Amsley-Benzie, Shelby

Shelby

I've been able to sort out a contact for you but have a couple more questions about timing and volume. I left you a message on your phone a few minutes ago. Please give me a call when you have a free minute. 865 429 6330.

Thanks

Bob

AS

Amsley-Benzie, Shelby

|

Thu 7/28

Bob,

I received your contact information from Johnson Matthey Chemicals and Catalysts. They thought you would be able to get me price on a catalyst you produce. I am looking for a bulk price quantity, as we are looking to purchase a large amount of the catalyst.

I am working through the University of North Dakota, and we had worked with your company about 10 years ago to purchase this same catalyst. At the time we were doing smaller scale testing, but are looking to increase this scale. The catalyst I am looking for is Ni/SiO_2 at 55 wt%. When we purchased it before it came as pellets with dimensions of 6 mm in diameter and 5 mm in height.

What I need is a price on this catalyst, or something similar, in bulk quantity. Please let me know if you will be able to help me.

Sincerely,
Shelby Amsley-Benzie
University of North Dakota
shelby.amsleybenzie@ndus.edu

218-301-9466

Hi Shelby,

My name is Abby Sup. We spoke on the phone earlier this week. I wanted to send over information on a pelleted nickel catalyst that Johnson Matthey manufactures to consider for your research work. I have attached a product bulletin of our KATALCO 11-4 for your review. The price range for this catalyst is $1,000/ft3. Catalysts are sold in full drum quantities (roughly 6 ft3 of catalyst per drum).

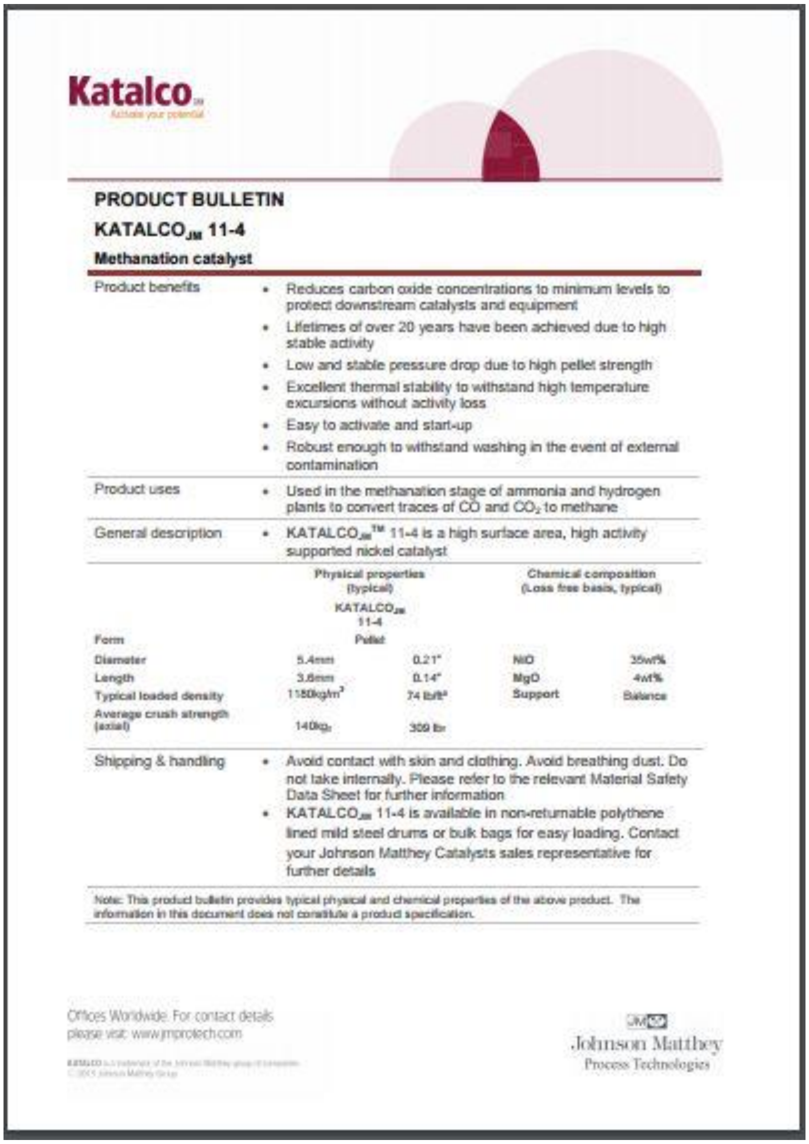
If looking for smaller quantities to purchase, I would recommend using Alfa Aesar at https://www.alfa.com/en/catalog/category/catalysts/ .

Let me know if you would like more information on KATALCO 11-4.

Best Regards,

Abby Sup
Technical Sales Manager
Johnson Matthey Inc.
2 Transam Plaza Dr. Suite 230
Oakbrook Terrace, IL 60181
USA

Office: +1 630-268-6328
Cell: +1 630-258-6397
E-mail: abigail.sup@matthey.com
www.jmprotech.com



Katalco JM
Activate your potential

PRODUCT BULLETIN

KATALCO$_{JM}$ 11-4

Methanation catalyst

Product benefits	• Reduces carbon oxide concentrations to minimum levels to protect downstream catalysts and equipment • Lifetimes of over 20 years have been achieved due to high stable activity • Low and stable pressure drop due to high pellet strength • Excellent thermal stability to withstand high temperature excursions without activity loss • Easy to activate and start-up • Robust enough to withstand washing in the event of external contamination
Product uses	• Used in the methanation stage of ammonia and hydrogen plants to convert traces of CO and CO_2 to methane
General description	• KATALCO$_{JM}$™ 11-4 is a high surface area, high activity supported nickel catalyst

	Physical properties (typical)		Chemical composition (Loss free basis, typical)	
	KATALCO$_{JM}$ 11-4			
Form	Pellet			
Diameter	5.4mm	0.21"	NiO	35wt%
Length	3.6mm	0.14"	MgO	4wt%
Typical loaded density	1180kg/m^3	74 lb/ft^3	Support	Balance
Average crush strength (axial)	140kg$_f$	309 lb$_f$		

Shipping & handling	• Avoid contact with skin and clothing. Avoid breathing dust. Do not take internally. Please refer to the relevant Material Safety Data Sheet for further information • KATALCO$_{JM}$ 11-4 is available in non-returnable polythene lined mild steel drums or bulk bags for easy loading. Contact your Johnson Matthey Catalysts sales representative for further details

Note: This product bulletin provides typical physical and chemical properties of the above product. The information in this document does not constitute a product specification.

Offices Worldwide. For contact details please visit: www.jmprotech.com

JM Johnson Matthey
Process Technologies

G.14. Vacuum Bottom Product Price

Vacuum Bottom Price

AS

Amsley-Benzie, Shelby

Reply all

8/4/2016

heathfleming@gmail.com

Heath,

I just called a few min ago inquiring about a price for your vacuum bottoms. We would use them as a feed stock to produce continuous carbon fibers from tars.

I am looking at needing roughly 300,000,000 lb/year sent to Grand Forks North Dakota. At this time I just need an idea of the price to bring to our supervisor.

Thank you for the help,

Shelby Amsley-Benzie
University of North Dakota
218-301-9466

TELEPHONE CONVERSATION RECORD

ORIGINATOR: Heath Fleming RECEIVER: Shelby Amsley-Benzie

PHONE NUMBER: 229-366-1313 PHONE NUMBER: Shelby Amsley-Benzie

DATE OF CALL: 8-4-2016 TIME OF CALL: 2:22 PM

APPROX. DURATION: 5 min

REASON FOR THE CALL: To receive a price quote on the vacuum bottoms products they sell.

Summarize the contents of the conversation below. Use exact quotations of important statements made by either party:

Health called me and asked a few questions about my process. He mostly wanted to know where we would be located, and if we would have access to railways, or if they would have to truck the shipment in. I explained that at this time I just need a rough price estimate for the cost. He then proceeded to do a little math, and provided me a number. He said that a typical rough cost would be $0.05 per pound.

RECORDED BY: Shelby Amsley-Benzie DATE: 8-5-2016

G.15. Propionic Acid Quote

CIGCHEMICALS@DOW.COM

Reply all

Today 1:37 AM

Amsley-Benzie, Shelby

Dear Ms. Shelby Amsley-Benzie,

Thank you for contacting the Dow Customer Information Group.

Your request has been received and forwarded on for handling under reference number -300534171

Please do not hesitate to contact us if you require further assistance.

Best regards,

Tejal Rathod

Customer Information Group (CIG)
on behalf of The Dow Chemical Company

North America

	Toll Free
Chemicals	+1 800 447 4369
Plastics	+1 800 441 4369
Dow Building Solutions	+1 866 583 2583

*******DO NOT DELETE********
{ticketno:[300534171]}
*******DO NOT DELETE********

Original Text

From: shelby.amsleybenzie@und.edu

To: CIGCHEMICALS@DOW.COM

CC:

Sent: 30.08.16 16:42:01
Subject: Re: EXT-NA-ENG-Propionic Acid-PRICE{ticketno:[201145799]}

Tejal Rathod,

We would be looking to use it in the biofuels industry as a solvent. We would not be looking to purchase for over a year. Right now we are working on a preliminary cost estimate in order to receive further funding, therefore, we need a rough idea of the price of the propionic acid.

Thank you,
Shelby

From: CIGCHEMICALS@DOW.COM <CIGCHEMICALS@DOW.COM>
Sent: Tuesday, August 30, 2016 12:52:52 AM
To: Amsley-Benzie, Shelby
Subject: RE: EXT-NA-ENG-Propionic Acid-PRICE{ticketno:[201145799]}

Dear Shelby Amsley-Benzie,
Thank you for contacting the Dow Customer Information Group.

In order to assist you in the most efficient manner, please provide the following information.
- Industry and Specific end use application (what is the end product that you are formulating/manufacturing?)

- Expected date of first purchase
As soon as we receive this information we will be able to process your request.
We appreciate your cooperation.
Best regards,

Tejal Rathod
Customer Information Group (CIG)
on behalf of The Dow Chemical Company

North America

	Toll Free
Chemicals	+1 800 447 4369
Plastics	+1 800 441 4369
Dow Building Solutions	+1 866 583 2583

*******DO NOT DELETE********
{ticketno:[201145799]}
*******DO NOT DELETE********

Original Text

From: SHELBY.AMSLEYBENZIE@NDUS.EDU
To: dowcig@dow.com
CC:
Sent: 29.08.16 21:20:51
Subject: EXT-NA-ENG-Propionic Acid-PRICE

UrlReferrer : http://www.dow.com:15732/en-us/contact-us-cig
Formname : DowContact
Language : ENGLISH
CourtesyResponse : Y
ClientSubject : The Dow Chemical Company Contact Us
sFName : Shelby
sLName : Amsley-Benzie
sCompany : University of North Dakota
sAddress : 241 Centennial Dr
sCity : Grand Forks
sProvince : North Dakota
sPostal : 58202
sCountry : United States
sPhone : 2183019466
sMobilePhone : 2183019466
sEmail : shelby.amsleybenzie@ndus.edu
sConfirmEmail : shelby.amsleybenzie@ndus.edu
Product1_sProduct: Propionic Acid
Product1_sApplicantEndUse : Commodity chemical
Product1_nature_of_request_pricing : yes
Product1_sPricingAndAvailabilityQuantity : 4,700,000 lb/year

TELEPHONE CONVERSATION RECORD

ORIGINATOR: Shelby Amsley-Benzie RECEIVER: Dane Farmer

PHONE NUMBER: 989-638-0346 PHONE NUMBER: 218-301-9466

DATE OF CALL: 8-31-2016 TIME OF CALL: 11:39 AM

APPROX. DURATION: 5 min

REASON FOR THE CALL: To receive a price quote for propionic acid.

Summarize the contents of the conversation below. Use exact quotations of important statements made by either party:

I returned a call to Dane Farmer of Dow chemical company. I had contacted them inquiring about pricing for propionic acid they sell. The email conversation provided most of the information he needed. When I talked to him he was able to provide me with a rough price estimate of what propionic acid has been selling for commercially. That would be $0.70/lb.

RECORDED BY: Shelby Amsley-Benzie DATE: 8-31-2016

G.16. Acetic Acid Price

Dustin Brudnicki <dustin.brudnicki@univarusa.com>

Reply all

Today 11:52 AM

Abby Bloxham <Abby.Bloxham@univarusa.com>;

Amsley-Benzie, Shelby

This message was sent with high importance.

Hi Abby,

Shelby called in today (218)301-9466 to inquire on pricing of Acetic Acid (97%). Her email is copied above.

She is looking for 20,000 lbs. per day. She did not know the size of their tank though.

Thanks Abby!

Univar will be closed on September 5th for the Labor Day Holiday

Dustin Brudnicki
Customer Service Representative
Direct Line: 708-325-2490
Univar

"Interested in accessing SDS's, COA's, Sales Orders, or Invoices online? Visit [customer.univar.com]Customer.Univar.com to sign up. If you would like to access only SDS's online without registering, visit [sds.univar.com]SDS.Univar.com."

Customer First: You're Univar's top priority.
Take our one-minute survey and tell us how we're doing.

All transactions are subject to Univar's Standard Terms & Conditions available at www.univarusa.com or upon request. Univar rejects all other terms and conditions unless otherwise agreed upon in writing by an authorized Univar representative.

Univar - Acetic Acid quote

AS

Amsley-Benzie, Shelby

Reply all|
Fri 9/9, 2:13 PM
Dylan Turner <dylan.turner@univar.com>
Sent Items

Dylan,

Thank you for the response. It is greatly appreciated.

-Shelby

DT

Dylan Turner <dylan.turner@univar.com>

|
Fri 9/9, 1:20 PM

Shelby,

Current Acetic Acid pricing is below:

Acetic Acid Full Truckload pricing - .62/#

It would be most cost effective if you are able to take full truckload deliveries depending on the size of your tank.

Thank you,

Dylan Turner
Account Manager
Univar
M (612) 616-0032
dylan.turner@univarusa.com

G.17. TMA Price Quote

WebQuote: University of North Dakota Re: Trimethylamine 25% Aqueous Solution

JF

jennifer fitzherbert <jenniferf@pentamfg.com>

Reply all

Fri 2/10, 4:45 PM

Amsley-Benzie, Shelby

Code# 20-76900

TRIMETHYLAMINE 25% AQUEOUS SOLUTION

Cas: 75-50-3

1,700/lbs.

$ 16.50/Lb.

Lead Time: 3 - 4 weeks

Pricing is FOB Livingston, NJ 07039

For any **technical questions**, please contact Lisa Amato in our technical services department at lisaa@pentamfg.com

For **documents**, please contact Fatima Jasmins in our technical services department at fatimaj@pentamfg.com or visit our website atwww.pentamfg.com

If you have any further questions, please feel free to contact me.

Thanks,

Jennifer Fitzherbert

Customer Service
Penta International Corporation 50 Okner Parkway Livingston, NJ 07039 USA
TEL: 1-973-740-2300 Ext. 127 / FAX: 1-973-740-1646
DIRECT EMAIL: JENNIFERF@PENTAMFG.COM WEBSITE: WWW.PENTAMFG.COM

Sent: Wednesday, February 8, 2017 12:26 PM
To: sales@pentamfg.com
Subject: Message from website

****This is a request forwarded from Penta Website****
Name: Shelby Amsley-Benzie
Title:
Company Name University of North Dakota
Address: 241 Centennial Dr
Address 2:
City: Grand Forks
State: North Dakota
Zip: 58202
Phone: 2183019466
Fax: 2183019466
E-mail: shelby.amsleybenzie@ndus.edu
Message: I am looking for a price quote on your 25% aqueous solution of TMA. We are looking at purchasing roughly 1700 lb.

Thank you

G.18. C9, C10, C11 Fatty Acid Price Quotes

Pelargonic Acid

AS

Amsley-Benzie, Shelby

Wed 2/8, 1:42 PM

Michael,

Thank you for the response. I will talk to my supervisor and we will be in touch.

-Shelby

ML

Michael Laux <ml@parchem.com>

Reply all|

Wed 2/8, 1:22 PM

Amsley-Benzie, Shelby

Action Items

Shelby,

Product: Pelargonic Acid
Quantity: 1 x 410 LB
Pack Type: Metal Drum
Quote: $6.15 / LB FOB NJ

Product: Decanoic Acid
Quantity: 1 x 410 LB
Pack Type: Metal Drum
Quote: $4.80 / LB FOB NJ

Standard lead times will apply.

I'll continue sourcing your Undecanoic Acid, please advise your comments on the above pricing.

Best regards,
Michael Laux

AS

Amsley-Benzie, Shelby

|

Wed 2/8, 1:07 PM

Michael,

Thank you for getting back to me so quickly.
I have no specific grade requirements in mind, but I would like it in the liquid form.
I was also wondering if you have decanoic and undecanoic acid for sale. If that is the case I would also like a quote for those acids as well.

We would be looking at purchasing the acids in bulk, so the largest orders you usually provide. The application would be we are looking into solvent extraction of acids on a commercial scale.

Thank you again,

Shelby

ML

Michael Laux <ml@parchem.com>

|
Wed 2/8, 12:03 PM

Hello Shelby,

Thank you for reaching out to Parchem, my name is Michael. I received your request for Pelargonic Acid.

To better assist you please provide me with the following details:

Specific grade requirements (if applicable)

Specific form requirements (if applicable)

Application of Product.

Forecasted annual demand.

Target price.

I look forward to working with you on this.

Following is Information for product	**WEB ID : 21912**

Customer Information:

Company:	University of North Dakota
Name:	Shelby Amsley-Benzie
Title:	
Email:	shelby.amsleybenzie@ndus.edu
Website:	241 Centennial Dr
Address:	241 Centennial Dr
Phone:	2183019466
City:	Grand Forks
State:	North Dakota
Zip:	58202
Country:	United States
Shipping Address:	241 Centennial Dr,,58202,Grand Forks,North Dakota,United States
Target Delivery:	9/11/2017
Notes:	We are looking to get a price quote on purchasing your nonanoic acid product. We are also looking into purchasing decanoic and undecanoic acid as well. If you provide these chemicals we would also like a quote on them. Thank you

http refferers Information:

Entry to site:	
IP:	134.129.205.210

Product Information:

Name	CAS	Qty	Unit
Pelargonic Acid	**112-05-0**	100	kg.

G.19. Petroleum Pitch Price Quote

Petroleum Pitch Sale Price

AS

Amsley-Benzie, Shelby

|

Today, 5:53 PM

Brett,

Thank you very much for the information. That helps a lot.

-Shelby

JM

Johnston, Brett M <JohnstonBM@koppers.com>

|

Today, 5:52 PM

Hi Shelby,

We no longer produce petroleum pitch products. However, we produce coal tar pitch. For 50,000 MT of annual supply, the price would be $550-650/MT FOB our plant.

Best regards,
Brett

Brett M. Johnston
Manager, Marketing and Sales, Carbon Pitch and Refined Tar
North American Operations
Carbon Materials and Chemicals
Koppers Inc. | 436 Seventh Avenue | Pittsburgh, PA 15219 | United States
T: + 412 227 2532 | M: +1 412 944 9789 | F: +1 412 227 2262
JohnstonBM@koppers.com

Responsible Care | A member of the American Chemistry Council
Learn more about Koppers: http://www.koppers.com

Amsley-Benzie, Shelby

Reply all

Today, 5:38 PM

JohnstonBM@koppers.com

Mr. Johnston,

I am currently working at the University of North Dakota, and have an inquiry about the price of a bulk petroleum pitch purchase. We are currently working on developing a process at the commercial level, and I am looking for a price quote on a bulk order of pitch. I just need a budgetary estimate at this point. We are looking for a number at the scale of 50,000,000 kg/year. I was wondering what type of bulk price we could get this amount of pitch at.

Thank you for the help.

Sincerely,
Shelby Amsley-Benzie
University of North Dakota
shelby.amsleybenzie@ndus.edu
218-301-9466

Appendix H. ChemCad Simulations

The following sections provide a list of the ChemCad simulations ran on each unit operation for the designs presented in Chapters III, IV, V and Appendix A in this thesis.

H.1. Base Design and Heavy End Processing (Mesophase Pitch Recovery) Design

H.1.i. Distillation Columns

D-201: Atmospheric Column

```
TOWR Rigorous Distillation Summary

Equip. No.                     14
       Name
No. of stages                   7
1st feed stage                  3
Top pressure  psia        18.0000
Condenser mode                  7
Condenser spec.            0.5000
Cond comp i                    18
Reboiler mode                   7
Reboiler spec.             0.9900
Reboiler comp i                94
Initial flag                    1
Calc cond duty  MJ/min  -119.5751
Calc rebr duty  MJ/min   354.0187
Est. Dist. rate            5.5732
 (lbmol/min)
Est. Reflux rate           5.2486
 (lbmol/min)
Est. T top  F            211.6549
Est. T bottom  F         711.7022
Est. T 2  F              493.2700
Tray type                       3
Column diameter  ft        8.0000
Tray space  ft             2.0000
Thickness (top)  ft        0.0052
Thickness (bot)  ft        0.0052
No of sections                  1
Bottom Pout  psia         25.0000
Calc Reflux ratio          0.0745
Calc Reflux mole           0.2193
 (lbmol/min)
Calc Reflux mass          27.9062
 (lb/min)
No of passes (S1)               1
Weir side width  ft        1.4583
Weir height  ft            0.1667
System factor              1.0000
Optimization flag               1
```

D-202: Vacuum Column

```
     TOWR Rigorous Distillation Summary

Equip. No.                      51
       Name
No. of stages                   20
1st feed stage                   5
Top pressure  psia            4.0000
Condenser mode                   7
Condenser spec.               0.9000
Cond comp i                     26
Reboiler mode                    7
Reboiler spec.                0.9900
Reboiler comp i                 29
Initial flag                     6
Calc cond duty  MJ/min    -263.1205
Calc rebr duty  MJ/min     207.6720
Est. Dist. rate               3.3561
 (lbmol/min)
Est. Reflux rate              3.5093
 (lbmol/min)
Est. T top  F               444.0000
Est. T bottom  F            669.0714
Est. T 2  F                 512.9335
Tray type                        3
Column diameter  ft           9.5000
Tray space  ft                2.0000
No of sections                   1
Bottom Pout  psia             6.0000
Calc Reflux ratio             1.3479
Calc Reflux mole              4.1485
 (lbmol/min)
Calc Reflux mass            940.3527
 (lb/min)
No of passes (S1)                1
Weir side width  ft           1.7083
Weir height  ft               0.1667
System factor                 1.0000
Optimization flag                1
```

D-204: Jet Diesel Cut Column

```
TOWR Rigorous Distillation Summary

Equip. No.                      26
       Name
No. of stages                   25
1st feed stage                  13
Top pressure  psia           15.0000
Condenser mode                   7
Condenser spec.               0.2500
Cond comp i                     20
Reboiler mode                    7
Reboiler spec.                0.9990
Reboiler comp i                 21
```

```
Initial flag                       1
Calc cond duty  MJ/min     -136.8654
Calc rebr duty  MJ/min      170.2632
Est. Dist. rate               2.6149
 (lbmol/min)
Est. Reflux rate              5.0238
 (lbmol/min)
Est. T top  F               100.0000
Est. T bottom  F            654.9268
Est. T 2  F                 517.7233
Tray type                          3
Column diameter  ft           8.5000
Tray space  ft                2.0000
Thickness (top)  ft           0.0052
Thickness (bot)  ft           0.0130
No of sections                     1
Bottom Pout  psia            25.0000
Calc Reflux ratio             1.5190
Calc Reflux mole              1.4942
 (lbmol/min)
Calc Reflux mass            247.6491
 (lb/min)
No of passes (S1)                  1
Weir side width  ft           1.5208
Weir height  ft               0.1667
System factor                 1.0000
Optimization flag                  1
```

D-205: Naphtha Jet Cut Column

```
Condenser spec.               1.2500
Cond comp i                       14
Reboiler mode                      7
Reboiler spec.                0.9965
Reboiler comp i                   73
Initial flag                       6
Calc cond duty  MJ/min      -75.3483
Calc rebr duty  MJ/min      116.2913
Est. Dist. rate               1.7214
 (lbmol/min)
Est. Reflux rate              2.1518
 (lbmol/min)
Est. T top  F                92.2112
Est. T bottom  F            415.8731
Est. T 2  F                 234.4917
Tray type                          3
Column diameter  ft           4.5000
Tray space  ft                2.0000
Thickness (top)  ft           0.0052
Thickness (bot)  ft           0.0286
No of sections                     1
Calc Reflux ratio             1.2500
Calc Reflux mole              1.9018
 (lbmol/min)
Calc Reflux mass            179.0563
 (lb/min)
```

No of passes (S1)	1
Weir side width ft	0.8333
Weir height ft	0.1667
System factor	1.0000
Optimization flag	1

D-206: Diesel Fuel Oil Cut Column

TOWR Rigorous Distillation Summary

Equip. No.	34
Name	
No. of stages	40
1st feed stage	28
Top pressure psia	20.0000
Cond pressure drop (psi)	5.0000
Colm pressure drop (psi)	5.0000
Condenser mode	7
Condenser spec.	0.9500
Cond comp i	26
Reboiler mode	7
Reboiler spec.	0.9900
Reboiler comp i	28
Initial flag	1
Calc cond duty MJ/min	-106.7084
Calc rebr duty MJ/min	117.2880
Est. Dist. rate (lbmol/min)	3.0575
Est. Reflux rate (lbmol/min)	7.6994
Est. T top F	603.0223
Est. T bottom F	883.3350
Est. T 2 F	625.3803
Tray type	3
Column diameter ft	8.0000
Tray space ft	2.0000
Thickness (top) ft	0.0078
Thickness (bot) ft	0.0286
No of sections	1
Calc Reflux ratio	0.7699
Calc Reflux mole (lbmol/min)	1.4790
Calc Reflux mass (lb/min)	363.1806
No of passes (S1)	1
Weir side width ft	1.4583
Weir height ft	0.1667
System factor	1.0000
Optimization flag	1

D-207: Syngas Column

TOWR Rigorous Distillation Summary

Equip. No.	115
Name	
No. of stages	40
1st feed stage	5
Top pressure psia	400.0000
Condenser type	1
Condenser mode	7
Condenser spec.	0.9700
Cond comp i	8
Reboiler mode	7
Reboiler spec.	0.9900
Reboiler comp i	9
Initial flag	1
Calc cond duty MJ/min	-27.5058
Calc rebr duty MJ/min	51.9438
Est. Dist. rate (lbmol/min)	13.0636
Est. Reflux rate (lbmol/min)	0.2556
Est. T top F	-6.8919
Est. T bottom F	344.0276
Tray type	3
Column diameter ft	7.0000
Tray space ft	2.0000
Thickness (top) ft	0.1250
Thickness (bot) ft	0.1250
No of sections	1
Calc Reflux ratio	0.3934
Calc Reflux mole (lbmol/min)	4.0980
Calc Reflux mass (lb/min)	169.2827
No of passes (S1)	1
Weir side width ft	1.2708
Weir height ft	0.1667
System factor	1.0000
Optimization flag	1

D-210: Debutanizer Column

TOWR Rigorous Distillation Summary

Equip. No.	66
Name	
No. of stages	12
1st feed stage	8
Top pressure psia	120.0000
Cond pressure drop (psi)	5.0000
Colm pressure drop (psi)	5.0000
Condenser type	1
Condenser mode	7
Condenser spec.	0.9500
Cond comp i	9

Reboiler mode	7
Reboiler spec.	0.9700
Reboiler comp i	10
Initial flag	1
Calc cond duty MJ/min	-36.2784
Calc rebr duty MJ/min	44.0522
Est. Dist. rate (lbmol/min)	1.7103
Est. Reflux rate (lbmol/min)	3.6289
Est. T top F	149.9970
Est. T bottom F	795.5644
Tray type	3
Column diameter ft	11.5000
Tray space ft	2.0000
Thickness (top) ft	0.0599
Thickness (bot) ft	0.0599
No of sections	1
Calc Reflux ratio	5.4368
Calc Reflux mole (lbmol/min)	4.3138
Calc Reflux mass (lb/min)	250.5444
No of passes (S1)	1
Weir side width ft	2.0833
Weir height ft	0.1667
System factor	1.0000
Optimization flag	1

H.1.ii. Flash Drums

D-101: Flash 1

Flash Summary

Equip. No.	7
Name	
Flash Mode	6
Param 1	100.0000
Heat duty MJ/min	-1.1231
Diameter ft	4.0000
Length ft	16.0000
Vessel thickness ft	0.0313
Head thickness ft	0.0313
Straight flange ft	0.1667
Metal density lb/ft3	489.0240

K values:	
triolein	0.024
Water	23.084
Hydrogen	85.813
Carbon Monoxide	71.026
Carbon Dioxide	31.460
Methane	47.577
Ethane	19.666
n-Propane	11.531

N-Butane	6.781
N-Pentane	4.112
N-Hexane	2.515
N-Heptane	1.590
N-Octane	1.005
N-Nonane	0.637
N-Decane	0.410
N-Undecane	0.266
N-Dodecane	0.172
N-Tridecane	0.113
N-Tetradecane	0.074
N-Pentadecane	0.049
N-Hexadecane	0.031
N-Heptadecane	0.022
N-Octadecane	0.016
N-Nonadecane	0.011
Eicosane	7.602E-003
uneicosane	4.857E-003
n-docosane	3.508E-003
n-tricosane	2.333E-003
n-Tetracosane	1.626E-003
n-pentacosane	1.166E-003
n-hexacosane	8.134E-004
N-Heptacosane	5.439E-004

n-Octacosane	4.229E-004
n-Nonacosane	3.231E-004
n-triacontane	2.343E-004
n-Dotriacontane	1.336E-004
n-Hexatriaconta	4.449E-005
2-Methyloctane	0.728
Cyclopentene	3.718
Methylcyclopent	2.336
Ethylcyclopenta	1.409
N-Propylcyclope	0.855
n-Butylcyclopen	0.562
N-Butylcyclohex	0.339
N-Hexylcyclo-C5	0.224
N-Octylcyclo-C5	0.095
N-Nonylcyclopen	0.061
N-Decylcyclopen	0.040
N-Decylcyclohex	0.025
N-Dodecylcyclop	0.019
N-Tridecylcyclo	0.013
Ethylene	23.352
Propylene	12.391
1-Butene	7.338
1-Pentene	4.476
1-Hexene	2.690
1-Heptene	1.696
1-Octene	1.067

1-Nonene	0.676
1-Decene	0.435
1-Undecene	0.282
1-Dodecene	0.183
1-Tridecene	0.120
1-Tetradecene	0.079
1-Pentadecene	0.052
1-Hexadecene	0.035
1-Heptadecene	0.024
1-Octadecene	0.016
1-Nonadecene	0.011
1-Eicosene	7.163E-003
Toluene	1.362
Ethylbenzene	0.863
N-Propylbenzene	0.560
1-butylbenzene	0.351
N-Pentylbenzene	0.222
N-Hexylbenzene	0.143
N-Heptylbenzene	0.091
N-Octylbenzene	0.059
N-Nonylbenzene	0.038
N-Dodecylbenzen	0.011

N-Decylbenzene	0.026
N-Undecylbenzen	0.017
Acetic Acid	1.802
Propionic Acid	1.142
N-Butyric Acid	0.739
Pentanoic Acid	0.439
N-Hexanoic Acid	0.281
Heptanoic Acid	0.183
N-Octanoic Acid	0.117
N-Nonanoic Acid	0.075
N-Decanoic Acid	0.048
undecanoic acid	0.033
Dodecanoic Acid	0.022
N-Tridecanoic A	0.015
N-Tetradecanoic	0.010
Pentadecanoic A	7.053E-003
N-Hexadecanoic	4.894E-003
Heptadecanoic A	3.442E-003
n-Octadecanoic	2.324E-003
Carbon	2.012E-008
Nitrogen	71.884
N-Heptylcyclope	0.143
Perylene	9.131E-004
pentacontane	7.827E-006
dopentacontane	6.030E-006
octatetracontan	1.003E-005
hexatetracontan	1.390E-005
tetratetraconta	1.957E-005

dotetracontane	2.488E-005
tetracontane	4.290E-005
octatriacontane	7.461E-005
tetratriacontan	2.226E-004
2-methyltetrade	0.061
Linolenic Acid	3.060E-003
Linoleic Acid	3.431E-003
Oleic Acid	2.818E-003
Benzene	2.281
O-Xylene	0.771
M-Xylene	0.827
P-Xylene	0.830
Indan	0.455
1-Methylindene	0.291
Naphthalene	0.238
1-Methylnaphtha	0.136
1-propylnaphtha	0.064
2,6-Dimethylnap	0.085
Sulfolane	0.097
Varsol	0.233

D-102: Flash 2

Flash Summary

Equip. No.	8
Name	
Flash Mode	6
Param 1	20.0000
Heat duty MJ/min	-0.8991
Type	1
Diameter ft	4.5000
Length ft	17.5812
Vessel thickness ft	0.0208
Head thickness ft	0.0208
Straight flange ft	0.1667
Metal density lb/ft3	489.0240

K values:	
triolein	1.120
Water	84.533
Hydrogen	570.651
Carbon Monoxide	402.815
Carbon Dioxide	132.945
Methane	247.357
Ethane	73.932
n-Propane	35.844
N-Butane	17.452
N-Pentane	8.821
N-Hexane	4.527
N-Heptane	2.395
N-Octane	1.272
N-Nonane	0.676
N-Decane	0.369
N-Undecane	0.204
N-Dodecane	0.112

N-Tridecane	0.062
N-Tetradecane	0.034
N-Pentadecane	0.020
N-Hexadecane	0.011
N-Heptadecane	6.508E-003
N-Octadecane	4.194E-003
N-Nonadecane	2.695E-003
Eicosane	1.503E-003
uneicosane	7.866E-004
n-docosane	5.035E-004
n-tricosane	2.811E-004
n-Tetracosane	1.687E-004
n-pentacosane	1.063E-004
n-hexacosane	6.368E-005

EQUIPMENT SUMMARIES

N-Heptacosane	3.558E-005
n-Octacosane	2.529E-005
n-Nonacosane	1.744E-005
n-triacontane	1.108E-005
n-Dotriacontane	5.067E-006
n-Hexatriaconta	1.077E-006
2-Methyloctane	0.825
Cyclopentene	7.926
Methylcyclopent	4.253
Ethylcyclopenta	2.146
N-Propylcyclope	1.127
n-Butylcyclopen	0.605
N-Butylcyclohex	0.343
N-Hexylcyclo-C5	0.170
N-Octylcyclo-C5	0.052
N-Nonylcyclopen	0.028
N-Decylcyclopen	0.016
N-Decylcyclohex	8.523E-003
N-Dodecylcyclop	5.597E-003
N-Tridecylcyclo	3.427E-003
Ethylene	93.049
Propylene	39.525
1-Butene	19.423
1-Pentene	9.578
1-Hexene	4.930
1-Heptene	2.641
1-Octene	1.402
1-Nonene	0.751
1-Decene	0.408
1-Undecene	0.222
1-Dodecene	0.121
1-Tridecene	0.068
1-Tetradecene	0.038
1-Pentadecene	0.021
1-Hexadecene	0.012
1-Heptadecene	7.238E-003

1-Octadecene	4.200E-003
1-Nonadecene	2.345E-003
1-Eicosene	1.368E-003
Toluene	2.044
Ethylbenzene	1.101
N-Propylbenzene	0.610
1-butylbenzene	0.321
N-Pentylbenzene	0.171
N-Hexylbenzene	0.093
N-Heptylbenzene	0.050
N-Octylbenzene	0.027
N-Nonylbenzene	0.015

EQUIPMENT SUMMARIES

N-Dodecylbenzen	2.778E-003
N-Decylbenzene	8.361E-003
N-Undecylbenzen	4.538E-003
Acetic Acid	2.625
Propionic Acid	1.341
N-Butyric Acid	0.704
Pentanoic Acid	0.346
N-Hexanoic Acid	0.186
Heptanoic Acid	0.104
N-Octanoic Acid	0.057
N-Nonanoic Acid	0.032
N-Decanoic Acid	0.017
undecanoic acid	0.010
Dodecanoic Acid	5.779E-003
N-Tridecanoic A	3.122E-003
N-Tetradecanoic	1.970E-003
Pentadecanoic A	1.197E-003
N-Hexadecanoic	6.775E-004
Heptadecanoic A	4.256E-004
n-Octadecanoic	2.626E-004
Carbon	7.597E-011
Nitrogen	419.381
N-Heptylcyclope	0.092
Perylene	1.154E-004
pentacontane	1.889E-007
dopentacontane	1.372E-007
octatetracontan	2.552E-007
hexatetracontan	3.870E-007
tetratetraconta	5.973E-007
dotetracontane	7.844E-007
tetracontane	1.671E-006
octatriacontane	3.586E-006
tetratriacontan	1.601E-005
2-methyltetrade	0.028
Linolenic Acid	3.283E-004
Linoleic Acid	3.847E-004
Oleic Acid	2.942E-004
Benzene	4.137

O-Xylene	0.944
M-Xylene	1.024
P-Xylene	1.033
Indan	0.473
1-Methylindene	0.260
Naphthalene	0.203
1-Methylnaphtha	0.095
1-propylnaphtha	0.033
2,6-Dimethylnap	0.049
Sulfolane	0.059

Varsol	0.173

D-103: Flash 3

Flash Summary	
Equip. No.	43
Name	
Flash Mode	6
Param 1	250.0000
Heat duty MJ/min	-0.6962
Type	1
Diameter ft	4.0000
Length ft	15.8430
Vessel thickness ft	0.0521
Head thickness ft	0.0521
Straight flange ft	0.1667
Metal density lb/ft3	489.0240

K values:	
triolein	0.016
Water	7.906
Hydrogen	37.529
Carbon Monoxide	29.352
Carbon Dioxide	11.711
Methane	18.255
Ethane	6.965
n-Propane	3.783
N-Butane	2.062
N-Pentane	1.162
N-Hexane	0.662
N-Heptane	0.389
N-Octane	0.229
N-Nonane	0.135
N-Decane	0.081
N-Undecane	0.049
N-Dodecane	0.030
N-Tridecane	0.018
N-Tetradecane	0.011
N-Pentadecane	6.864E-003

N-Hexadecane	4.047E-003
N-Heptadecane	2.687E-003
N-Octadecane	1.831E-003
N-Nonadecane	1.254E-003
Eicosane	7.727E-004
uneicosane	4.524E-004
n-docosane	3.093E-004
n-tricosane	1.904E-004
n-Tetracosane	1.241E-004
n-pentacosane	8.405E-005
n-hexacosane	5.468E-005

EQUIPMENT SUMMARIES

N-Heptacosane	3.380E-005
n-Octacosane	2.516E-005
n-Nonacosane	1.834E-005
n-triacontane	1.251E-005
n-Dotriacontane	6.430E-006
n-Hexatriaconta	1.741E-006
2-Methyloctane	0.158
Cyclopentene	1.071
Methylcyclopent	0.624
Ethylcyclopenta	0.351
N-Propylcyclope	0.201
n-Butylcyclopen	0.121
N-Butylcyclohex	0.072
N-Hexylcyclo-C5	0.041
N-Octylcyclo-C5	0.015
N-Nonylcyclopen	9.059E-003
N-Decylcyclopen	5.623E-003
N-Decylcyclohex	3.353E-003
N-Dodecylcyclop	2.291E-003
N-Tridecylcyclo	1.492E-003
Ethylene	8.480
Propylene	4.119
1-Butene	2.281
1-Pentene	1.263
1-Hexene	0.714
1-Heptene	0.421
1-Octene	0.247
1-Nonene	0.146
1-Decene	0.087
1-Undecene	0.053
1-Dodecene	0.032
1-Tridecene	0.019
1-Tetradecene	0.012
1-Pentadecene	7.346E-003
1-Hexadecene	4.586E-003
1-Heptadecene	2.948E-003
1-Octadecene	1.854E-003
1-Nonadecene	1.139E-003
1-Eicosene	7.231E-004

Toluene	0.340
Ethylbenzene	0.201
N-Propylbenzene	0.122
1-butylbenzene	0.071
N-Pentylbenzene	0.042
N-Hexylbenzene	0.025
N-Heptylbenzene	0.015
N-Octylbenzene	9.027E-003
N-Nonylbenzene	5.375E-003

EQUIPMENT SUMMARIES

N-Dodecylbenzen	1.314E-003
N-Decylbenzene	3.354E-003
N-Undecylbenzen	2.022E-003
Acetic Acid	0.446
Propionic Acid	0.255
N-Butyric Acid	0.151
Pentanoic Acid	0.083
N-Hexanoic Acid	0.050
Heptanoic Acid	0.030
N-Octanoic Acid	0.018
N-Nonanoic Acid	0.011
N-Decanoic Acid	6.605E-003
undecanoic acid	4.238E-003
Dodecanoic Acid	2.656E-003
N-Tridecanoic A	1.629E-003
N-Tetradecanoic	1.071E-003
Pentadecanoic A	7.019E-004
N-Hexadecanoic	4.422E-004
Heptadecanoic A	2.960E-004
n-Octadecanoic	1.926E-004
Carbon	6.200E-010
Nitrogen	30.140
N-Heptylcyclope	0.025
Perylene	8.498E-005
pentacontane	3.035E-007
dopentacontane	2.270E-007
octatetracontan	3.999E-007
hexatetracontan	5.780E-007
tetratetraconta	8.506E-007
dotetracontane	1.108E-006
tetracontane	2.084E-006
octatriacontane	3.958E-006
tetratriacontan	1.399E-005
2-methyltetrade	9.054E-003
Linolenic Acid	2.475E-004
Linoleic Acid	2.817E-004
Oleic Acid	2.246E-004
Benzene	0.615
O-Xylene	0.177
M-Xylene	0.190
P-Xylene	0.191

Indan	0.098
1-Methylindene	0.059
Naphthalene	0.048
1-Methylnaphtha	0.025
1-propylnaphtha	0.011
2,6-Dimethylnap	0.015
Sulfolane	0.017

Varsol	0.043
Ethylene Glycol	0.188
Air	23.304
Oxygen	20.935

D-104: Flash 4

Flash Summary	
Equip. No.	19
Name	
Flash Mode	6
Param 1	15.0000
Heat duty MJ/min	-1.7531
Type	1
Diameter ft	4.0000
Length ft	15.4435
Vessel thickness ft	0.0208
Head thickness ft	0.0208
Straight flange ft	0.1667
Metal density lb/ft3	489.0240

K values:	
triolein	0.080
Water	136.045
Hydrogen	641.145
Carbon Monoxide	489.275
Carbon Dioxide	184.671
Methane	297.552
Ethane	107.268
n-Propane	55.962
N-Butane	29.322
N-Pentane	15.866
N-Hexane	8.675
N-Heptane	4.907
N-Octane	2.773
N-Nonane	1.570
N-Decane	0.907
N-Undecane	0.531
N-Dodecane	0.307
N-Tridecane	0.180
N-Tetradecane	0.107
N-Pentadecane	0.064

N-Hexadecane	0.036
N-Heptadecane	0.023
N-Octadecane	0.015
N-Nonadecane	0.010
Eicosane	6.023E-003
uneicosane	3.378E-003
n-docosane	2.232E-003
n-tricosane	1.321E-003
n-Tetracosane	8.303E-004
n-pentacosane	5.444E-004
n-hexacosane	3.408E-004

EQUIPMENT SUMMARIES

N-Heptacosane	2.026E-004
n-Octacosane	1.464E-004
n-Nonacosane	1.037E-004
n-triacontane	6.842E-005
n-Dotriacontane	3.299E-005
n-Hexatriaconta	7.931E-006
2-Methyloctane	1.865
Cyclopentene	14.591
Methylcyclopent	8.257
Ethylcyclopenta	4.457
N-Propylcyclope	2.457
n-Butylcyclopen	1.424
N-Butylcyclohex	0.819
N-Hexylcyclo-C5	0.448
N-Octylcyclo-C5	0.153
N-Nonylcyclopen	0.087
N-Decylcyclopen	0.052
N-Decylcyclohex	0.030
N-Dodecylcyclop	0.019
N-Tridecylcyclo	0.012
Ethylene	131.851
Propylene	61.264
1-Butene	32.350
1-Pentene	17.314
1-Hexene	9.418
1-Heptene	5.354
1-Octene	3.017
1-Nonene	1.716
1-Decene	0.990
1-Undecene	0.574
1-Dodecene	0.334
1-Tridecene	0.197
1-Tetradecene	0.116
1-Pentadecene	0.069
1-Hexadecene	0.041
1-Heptadecene	0.026
1-Octadecene	0.016
1-Nonadecene	9.258E-003
1-Eicosene	5.666E-003

Toluene	4.332
Ethylbenzene	2.477
N-Propylbenzene	1.452
1-butylbenzene	0.815
N-Pentylbenzene	0.461
N-Hexylbenzene	0.266
N-Heptylbenzene	0.151
N-Octylbenzene	0.088
N-Nonylbenzene	0.051

EQUIPMENT SUMMARIES

N-Dodecylbenzen	0.011
N-Decylbenzene	0.030
N-Undecylbenzen	0.018
Acetic Acid	5.758
Propionic Acid	3.195
N-Butyric Acid	1.822
Pentanoic Acid	0.963
N-Hexanoic Acid	0.554
Heptanoic Acid	0.328
N-Octanoic Acid	0.190
N-Nonanoic Acid	0.111
N-Decanoic Acid	0.064
undecanoic acid	0.039
Dodecanoic Acid	0.024
N-Tridecanoic A	0.014
N-Tetradecanoic	8.966E-003
Pentadecanoic A	5.683E-003
N-Hexadecanoic	3.469E-003
Heptadecanoic A	2.249E-003
n-Octadecanoic	1.415E-003
Carbon	2.773E-009
Nitrogen	503.384
N-Heptylcyclope	0.257
Perylene	6.344E-004
pentacontane	1.178E-006
dopentacontane	8.556E-007
octatetracontan	1.599E-006
hexatetracontan	2.390E-006
tetratetraconta	3.649E-006
dotetracontane	4.919E-006
tetracontane	9.676E-006
octatriacontane	1.925E-005
tetratriacontan	7.474E-005
2-methyltetrade	0.085
Linolenic Acid	1.858E-003
Linoleic Acid	2.123E-003
Oleic Acid	1.666E-003
Benzene	8.168
O-Xylene	2.167
M-Xylene	2.331
P-Xylene	2.344

Indan	1.169
1-Methylindene	0.678
Naphthalene	0.547
1-Methylnaphtha	0.276
1-propylnaphtha	0.108
2,6-Dimethylnap	0.153
Sulfolane	0.187

EQUIPMENT SUMMARIES

Varsol	0.463
Ethylene Glycol	2.331
Air	385.281
Oxygen	344.551

D-105: Flash 5

Flash Summary	
Equip. No.	46
Name	
Flash Mode	6
Param 1	15.0000
Heat duty MJ/min	-6.2597
Type	1
Diameter ft	4.5000
Length ft	6.3057
Vessel thickness ft	0.0208
Head thickness ft	0.0208
Straight flange ft	0.1667
Metal density lb/ft3	489.0240

K values:	
triolein	4.643E+010
Water	21.607
Hydrogen	1118.715
Carbon Monoxide	588.190
Carbon Dioxide	65.411
Methane	207.581
Ethane	29.247
n-Propane	7.663
N-Butane	2.051
N-Pentane	0.592
N-Hexane	0.175
N-Heptane	0.053
N-Octane	0.017
N-Nonane	5.093E-003
N-Decane	1.731E-003
N-Undecane	5.740E-004
N-Dodecane	1.958E-004
N-Tridecane	6.274E-005
N-Tetradecane	2.147E-005
N-Pentadecane	7.777E-006

N-Hexadecane	2.732E-006
N-Heptadecane	1.184E-006
N-Octadecane	5.729E-007
N-Nonadecane	2.758E-007
Eicosane	8.803E-008
uneicosane	2.444E-008
n-docosane	1.152E-008
n-tricosane	3.754E-009
n-Tetracosane	1.467E-009
n-pentacosane	6.375E-010
n-hexacosane	2.497E-010

N-Heptacosane	7.895E-011
n-Octacosane	4.665E-011
n-Nonacosane	2.480E-011
n-triacontane	1.094E-011
n-Dotriacontane	2.910E-012
n-Hexatriaconta	1.842E-013
2-Methyloctane	7.892E-003
Cyclopentene	0.477
Methylcyclopent	0.164
Ethylcyclopenta	0.048
N-Propylcyclope	0.017
n-Butylcyclopen	4.628E-003
N-Butylcyclohex	2.667E-003
N-Hexylcyclo-C5	4.648E-004
N-Octylcyclo-C5	5.635E-005
N-Nonylcyclopen	1.855E-005
N-Decylcyclopen	6.920E-006
N-Decylcyclohex	1.939E-006
N-Dodecylcyclop	1.279E-006
N-Tridecylcyclo	5.880E-007
Ethylene	43.921
Propylene	8.957
1-Butene	2.453
1-Pentene	0.590
1-Hexene	0.198
1-Heptene	0.065
1-Octene	0.021
1-Nonene	6.693E-003
1-Decene	2.144E-003
1-Undecene	6.741E-004
1-Dodecene	2.066E-004
1-Tridecene	7.579E-005
1-Tetradecene	2.662E-005
1-Pentadecene	9.331E-006
1-Hexadecene	3.384E-006
1-Heptadecene	1.362E-006
1-Octadecene	5.023E-007
1-Nonadecene	1.683E-007
1-Eicosene	6.356E-008

Toluene	0.040
Ethylbenzene	0.013
N-Propylbenzene	4.485E-003
1-butylbenzene	1.357E-003
N-Pentylbenzene	4.307E-004
N-Hexylbenzene	1.439E-004
N-Heptylbenzene	4.499E-005
N-Octylbenzene	1.509E-005
N-Nonylbenzene	4.301E-006

N-Dodecylbenzen	2.326E-007
N-Decylbenzene	1.535E-006
N-Undecylbenzen	4.635E-007
Acetic Acid	0.035
Propionic Acid	8.490E-003
N-Butyric Acid	2.119E-003
Pentanoic Acid	5.786E-004
N-Hexanoic Acid	1.746E-004
Heptanoic Acid	5.968E-005
N-Octanoic Acid	2.050E-005
N-Nonanoic Acid	7.566E-006
N-Decanoic Acid	2.509E-006
undecanoic acid	9.341E-007
Dodecanoic Acid	3.305E-007
N-Tridecanoic A	7.867E-008
N-Tetradecanoic	4.816E-008
Pentadecanoic A	2.024E-008
N-Hexadecanoic	5.564E-009
Heptadecanoic A	2.656E-009
n-Octadecanoic	1.430E-009
Carbon	1.000E-020
Nitrogen	687.356
N-Heptylcyclope	1.611E-004
Perylene	1.105E-009
pentacontane	1.750E-013
dopentacontane	1.251E-013
octatetracontan	2.327E-013
hexatetracontan	4.055E-013
tetratetraconta	7.024E-013
dotetracontane	7.712E-013
tetracontane	3.227E-012
octatriacontane	1.327E-011
tetratriacontan	1.969E-010
2-methyltetrade	2.084E-005
Linolenic Acid	1.072E-009
Linoleic Acid	1.514E-009
Oleic Acid	9.312E-010
Benzene	0.149
O-Xylene	9.621E-003
M-Xylene	0.011
P-Xylene	0.011

Indan	2.787E-003
1-Methylindene	9.906E-004
Naphthalene	6.407E-004
1-Methylnaphtha	1.635E-004
1-propylnaphtha	2.064E-005
2,6-Dimethylnap	4.387E-005
Sulfolane	5.025E-005

Varsol	4.122E-004
Ethylene Glycol	4.874E-003
Air	414.930
Oxygen	308.166

D-107: Acetic Flash 1

Three Phase Flash Summary

Equip. No.	39
Name	
Flash Mode	1
Param1	420.0000
Param2	200.0000
Heat duty MJ/min	-25.8485

D-108: Acetic Flash 2

Three Phase Flash Summary

Equip. No.	65
Name	
Flash Mode	1
Param1	146.0000
Param2	30.0000
Heat duty MJ/min	18.7536

D-109: Flash 7

Flash Summary

Equip. No.	6
Name	
Flash Mode	6
Param 1	15.0000
Heat duty MJ/min	-2.9505

K values:

triolein	7224.442
Water	64.231
Hydrogen	811.258
Carbon Monoxide	575.464

Carbon Dioxide	119.297
Methane	251.012
Ethane	58.522
n-Propane	21.417
N-Butane	7.960
N-Pentane	3.104
N-Hexane	1.231
N-Heptane	0.505
N-Octane	0.211
N-Nonane	0.087
N-Decane	0.038
N-Undecane	0.017
N-Dodecane	7.315E-003
N-Tridecane	3.152E-003
N-Tetradecane	1.405E-003
N-Pentadecane	6.458E-004
N-Hexadecane	2.822E-004
N-Heptadecane	1.472E-004
N-Octadecane	8.233E-005
N-Nonadecane	4.587E-005
Eicosane	1.983E-005
uneicosane	7.777E-006
n-docosane	4.282E-006
n-tricosane	1.866E-006
n-Tetracosane	9.154E-007
n-pentacosane	4.839E-007
n-hexacosane	2.369E-007
N-Heptacosane	1.022E-007
n-Octacosane	6.577E-008
n-Nonacosane	3.990E-008
n-triacontane	2.130E-008
n-Dotriacontane	7.435E-009
n-Hexatriaconta	8.818E-010
2-Methyloctane	0.118

Cyclopentene	2.687
Methylcyclopent	1.166
Ethylcyclopenta	0.457
N-Propylcyclope	0.200
n-Butylcyclopen	0.079
N-Butylcyclohex	0.044
N-Hexylcyclo-C5	0.014
N-Octylcyclo-C5	2.721E-003
N-Nonylcyclopen	1.159E-003
N-Decylcyclopen	5.387E-004
N-Decylcyclohex	2.190E-004
N-Dodecylcyclop	1.368E-004
N-Tridecylcyclo	7.221E-005
Ethylene	80.159
Propylene	24.279
1-Butene	9.142

1-Pentene	3.271
1-Hexene	1.373
1-Heptene	0.586
1-Octene	0.246
1-Nonene	0.104
1-Decene	0.044
1-Undecene	0.019
1-Dodecene	7.908E-003
1-Tridecene	3.626E-003
1-Tetradecene	1.632E-003
1-Pentadecene	7.362E-004
1-Hexadecene	3.400E-004
1-Heptadecene	1.679E-004
1-Octadecene	7.889E-005
1-Nonadecene	3.479E-005
1-Eicosene	1.654E-005
Toluene	0.420
Ethylbenzene	0.178
N-Propylbenzene	0.079
1-butylbenzene	0.032
N-Pentylbenzene	0.014
N-Hexylbenzene	5.889E-003
N-Heptylbenzene	2.459E-003
N-Octylbenzene	1.077E-003
N-Nonylbenzene	4.333E-004
N-Dodecylbenzen	4.537E-005
N-Decylbenzene	1.988E-004
N-Undecylbenzen	8.270E-005
Acetic Acid	0.468
Propionic Acid	0.172
N-Butyric Acid	0.065
Pentanoic Acid	0.024

EQUIPMENT SUMMARIES

N-Hexanoic Acid	0.010
Heptanoic Acid	4.521E-003
N-Octanoic Acid	1.997E-003
N-Nonanoic Acid	9.125E-004
N-Decanoic Acid	3.937E-004
undecanoic acid	1.875E-004
Dodecanoic Acid	8.603E-005
N-Tridecanoic A	3.247E-005
N-Tetradecanoic	1.969E-005
Pentadecanoic A	1.004E-005
N-Hexadecanoic	4.134E-006
Heptadecanoic A	2.264E-006
n-Octadecanoic	1.285E-006
Carbon	1.405E-015
Nitrogen	635.867
N-Heptylcyclope	6.030E-003
Perylene	7.115E-007
pentacontane	2.609E-010

dopentacontane	1.835E-010
octatetracontan	3.595E-010
hexatetracontan	5.933E-010
tetratetraconta	9.904E-010
dotetracontane	1.249E-009
tetracontane	3.615E-009
octatriacontane	1.046E-008
tetratriacontan	8.156E-008
2-methyltetrade	1.203E-003
Linolenic Acid	1.338E-006
Linoleic Acid	1.695E-006
Oleic Acid	1.172E-006
Benzene	1.125
O-Xylene	0.143
M-Xylene	0.158
P-Xylene	0.161
Indan	0.056
1-Methylindene	0.025
Naphthalene	0.018
1-Methylnaphtha	6.431E-003
1-propylnaphtha	1.415E-003
2,6-Dimethylnap	2.465E-003
Sulfolane	2.998E-003
Varsol	0.013
Ethylene Glycol	0.111
Air	423.231
Oxygen	345.832

H.1.iii. Heat Exchangers

E-201 A/B: Cracking Cross Exchanger

Heat Exchanger Summary

Equip. No.	2
Name	
1st Stream dp psi	5.0000
2nd Stream dp psi	5.0000
1st Stream T Out F	439.0000
U Btu/hr-ft2-F	700.0000
Calc Ht Duty MJ/min	690.1989
LMTD (End points) F	287.9161
LMTD Corr Factor	1.0000
Calc U Btu/hr-ft2-F	700.0000
Calc Area ft2	194.7531
1st Stream Pout psia	255.0000
2nd Stream Pout psia	15.0000
P1 out specifed psia	255.0000
P2 out specifed psia	15.0000

E-202 A/B: Flash 2 Cooler

Heat Exchanger Summary

Equip. No.	9
Name	

1st Stream dp psi	5.0000
2nd Stream dp psi	5.0000
1st Stream T Out F	300.0000
2nd Stream VF Out	1.0000
Calc Ht Duty MJ/min	130.7119
LMTD (End points) F	172.6354
LMTD Corr Factor	1.0000
Utility Option:	1
1st Stream Pout psia	95.0000
2nd Stream Pout psia	50.0000
P1 out specifed psia	95.0000
P2 out specifed psia	50.0000

E-204 A/B: Light End Cooler

Heat Exchanger Summary

Equip. No.	37
Name	
1st Stream dp psi	5.0000
2nd Stream dp psi	5.0000
1st Stream T Out F	90.0000
2nd Stream T Out F	113.0000
Calc Ht Duty MJ/min	68.4936
LMTD (End points) F	46.5123
LMTD Corr Factor	1.0000
Utility Option:	1
1st Stream Pout psia	455.0000
2nd Stream Pout psia	50.0000
P1 out specifed psia	455.0000
P2 out specifed psia	50.0000

E-205 A/B: Debutanizer Cooler

Heat Exchanger Summary

Equip. No.	71
Name	
1st Stream dp psi	5.0000
1st Stream T Out F	250.0000
Calc Ht Duty MJ/min	-16.5437
LMTD Corr Factor	1.0000
1st Stream Pout psia	395.0000
P1 out specifed psia	395.0000

E-207 A/B: Pre-Flash 5 Cooler

Heat Exchanger Summary

Equip. No.	67
Name	
1st Stream dp psi	5.0000
2nd Stream dp psi	5.0000
1st Stream T Out F	100.0000
2nd Stream T Out F	113.0000

```
Calc Ht Duty  MJ/min        19.4297
LMTD (End points)  F        34.7452
LMTD Corr Factor             1.0000
Utility Option:                 1
1st Stream Pout  psia       25.0000
2nd Stream Pout  psia       50.0000
P1 out specifed  psia       25.0000
P2 out specifed  psia       50.0000
```

E-208 A/B: Post Diesel Decarbox Cooler

```
Heat Exchanger Summary

Equip. No.                     27
       Name
1st Stream dp  psi           5.0000
2nd Stream dp  psi           5.0000
1st Stream T Out  F        350.0000
2nd Stream T Out  F        113.0000
Calc Ht Duty  MJ/min       134.9829
LMTD (End points)  F       367.4783
LMTD Corr Factor             1.0000
Utility Option:                 1
1st Stream Pout  psia      315.0000
2nd Stream Pout  psia       50.0000
P1 out specifed  psia      315.0000
P2 out specifed  psia       50.0000
```

E-209 A/B: Post Naphtha Decarbox Cooler

```
   Heat Exchanger Summary

Equip. No.                     40
       Name
1st Stream dp  psi           5.0000
2nd Stream dp  psi           5.0000
1st Stream T Out  F        200.0000
2nd Stream T Out  F        113.0000
Calc Ht Duty  MJ/min       174.8056
LMTD (End points)  F       259.4733
LMTD Corr Factor             1.0000
Utility Option:                 1
1st Stream Pout  psia      315.0000
2nd Stream Pout  psia       50.0000
P1 out specifed  psia      315.0000
P2 out specifed  psia       50.0000
```

E-210 A/B: Interstage Cooler 1

```
Heat Exchanger Summary

Equip. No.                     82
       Name
1st Stream dp  psi           5.0000
2nd Stream dp  psi           5.0000
```

```
1st Stream T Out  F        140.0000
2nd Stream T Out  F        113.0000
Calc Ht Duty  MJ/min        35.2098
LMTD (End points)  F       109.2682
LMTD Corr Factor             1.0000
Utility Option:                 1
1st Stream Pout  psia       55.0000
2nd Stream Pout  psia       50.0000
P1 out specifed  psia       55.0000
P2 out specifed  psia       50.0000
```

E-211 A/B: Interstage Cooler 2

```
  Heat Exchanger Summary

Equip. No.                     83
       Name
1st Stream dp  psi           5.0000
2nd Stream dp  psi           5.0000
1st Stream T Out  F        190.0000
2nd Stream T Out  F        113.0000
Calc Ht Duty  MJ/min        42.8812
LMTD (End points)  F       168.7073
LMTD Corr Factor             1.0000
Utility Option:                 1
1st Stream Pout  psia      215.0000
2nd Stream Pout  psia       50.0000
P1 out specifed  psia      215.0000
P2 out specifed  psia       50.0000
```

E-502 A/B: TTCR Preheat

```
Heat Exchanger Summary

Equip. No.                     74
       Name
1st Stream dp  psi           5.0000
2nd Stream dp  psi           5.0000
1st Stream T Out  F        770.0001
2nd Stream T Out  F        700.0001
Calc Ht Duty  MJ/min       303.2726
LMTD (End points)  F        72.7786
LMTD Corr Factor             1.0000
Utility Option:                 1
1st Stream Pout  psia      275.0000
2nd Stream Pout  psia      870.0000
P1 out specifed  psia      275.0000
P2 out specifed  psia      870.0000
```

E-503 A/B: Naphtha Decarbox Heater

```
Heat Exchanger Summary

Equip. No.                     17
       Name
```

```
1st Stream dp  psi           5.0000
1st Stream T Out  F        608.0001
Calc Ht Duty  MJ/min       176.6798
LMTD Corr Factor             1.0000
1st Stream Pout  psia      345.0000
P1 out specifed  psia      345.0000
```

E-504 A/B: Diesel Decarbox Heater

```
Heat Exchanger Summary

Equip. No.                     24
       Name
1st Stream dp  psi           5.0000
1st Stream T Out  F        608.0001
Calc Ht Duty  MJ/min        86.5038
LMTD Corr Factor             1.0000
1st Stream Pout  psia      345.0000
P1 out specifed  psia      345.0000
```

E-505 A/B: Pre Jet Diesel Cut Heat

```
Heat Exchanger Summary

Equip. No.                     68
       Name
1st Stream dp  psi           5.0000
2nd Stream dp  psi           5.0000
1st Stream T Out  F        400.0000
2nd Stream VF Out       1.0000e-005
Calc Ht Duty  MJ/min        25.6697
LMTD (End points)  F        88.4139
LMTD Corr Factor             1.0000
Utility Option:                 1
1st Stream Pout  psia       25.0000
2nd Stream Pout  psia      473.0000
P1 out specifed  psia       25.0000
P2 out specifed  psia      473.0000
```

E-506 A/B: Pitching Preheat

```
Heat Exchanger Summary

Equip. No.                     45
       Name
1st Stream dp  psi           5.0000
1st Stream T Out  F        770.0001
Calc Ht Duty  MJ/min       113.5927
LMTD Corr Factor             1.0000
1st Stream Pout  psia        1.0000
P1 out specifed  psia        1.0000
```

E-1101 A/B: Jet Cooler

```
Heat Exchanger Summary

Equip. No.                        31
       Name
1st Stream dp  psi            1.0000
1st Stream T Out  F          90.0000
Calc Ht Duty  MJ/min        -57.8072
LMTD Corr Factor              1.0000
1st Stream Pout  psia        14.0000
P1 out specifed  psia        14.0000
```

E-1102 A/B: Diesel Cooler

```
Heat Exchanger Summary

Equip. No.                        32
       Name
1st Stream dp  psi            1.0000
1st Stream T Out  F         140.0000
Calc Ht Duty  MJ/min       -145.7071
LMTD Corr Factor              1.0000
1st Stream Pout  psia        19.0000
P1 out specifed  psia        19.0000
```

E-1103 A/B: Fuel Oil Cooler 1

```
   Heat Exchanger Summary

Equip. No.                        29
       Name
1st Stream dp  psi            1.0000
1st Stream T Out  F         140.0000
Calc Ht Duty  MJ/min         -3.8230
LMTD Corr Factor              1.0000
1st Stream Pout  psia        29.0000
P1 out specifed  psia        29.0000
```

E-1104 A/B: Fuel Oil Cooler 2

```
Heat Exchanger Summary

Equip. No.                        47
       Name
1st Stream T Out  F         140.0000
Calc Ht Duty  MJ/min       -213.4558
LMTD Corr Factor              1.0000
1st Stream Pout  psia         1.0000
P1 out specifed  psia         1.0000
```

H.1.iv. Compressors

G-101 A/B: Flash 2 Compressor

```
   Compressor Summary
```

```
Equip. No.                    12
       Name
Pressure out  psia         60.0000
Type of Compressor             1
Efficiency                  0.5500
Actual power  MJ/min        1.0062
Cp/Cv                       1.0739
Theoretical power           0.5534
 (MJ/min)
Ideal Cp/Cv                 1.0686
Calc Pout  psia            60.0000
Calc. mass flowrate           20
 (lb/min)
```

G-103 A/B: Flash 5 Compressor

```
Compressor Summary

Equip. No.                    21
       Name
Pressure out  psia         35.0000
Type of Compressor             1
Efficiency                  0.5500
Actual power  MJ/min        0.9004
Cp/Cv                       1.0779
Theoretical power           0.4952
 (MJ/min)
Ideal Cp/Cv                 1.0750
Calc Pout  psia            35.0000
Calc. mass flowrate           23
 (lb/min)
```

G-105 Stage 1: Light End Compressor

```
                      Compressor Summary

Equip. No.                    79
       Name
Pressure out  psia         60.0000
Type of Compressor             1
Efficiency                  0.5500
Actual power  MJ/min       41.0964
Cp/Cv                       1.1844
Theoretical power          22.6030
 (MJ/min)
Ideal Cp/Cv                 1.1787
Calc Pout  psia            60.0000
Calc. mass flowrate          526
 (lb/min)
```

G-105 Stage 2: Light End Compressor

```
   Compressor Summary
```

Equip. No.	80
Name	
Pressure out psia	220.0000
Type of Compressor	1
Efficiency	0.5000
Actual power MJ/min	47.2979
Cp/Cv	1.1844
Theoretical power (MJ/min)	23.6490
Ideal Cp/Cv	1.1675
Calc Pout psia	220.0000
Calc. mass flowrate (lb/min)	526

G-105 Stage 3: Light End Compressor

Compressor Summary

Equip. No.	81
Name	
Pressure out psia	460.0000
Type of Compressor	1
Efficiency	0.5500
Actual power MJ/min	23.0560
Cp/Cv	1.2064
Theoretical power (MJ/min)	12.6808
Ideal Cp/Cv	1.1518
Calc Pout psia	460.0000
Calc. mass flowrate (lb/min)	526

H.1.v. Pumps

L-101 A/B: PreCracking Pump

Pump Summary

Equip. No.	3	4
Name		
Output pressure psia	40.0000	280.0000
Efficiency	0.6500	0.6500
Calculated power (MJ/min)	0.3893	3.8936
Calculated Pout psia	40.0000	280.0000
Head ft	84.7726	847.8664
Vol. flow rate (ft3/min)	51.8054	51.8141
Mass flow rate lb/min	2200.0000	2200.0000

L-103 A/B: Pre Naphtha Decarbox

Pump Summary

```
Equip. No.                    16
       Name
Output pressure  psia      350.0000
Efficiency                   0.6500
Calculated power             1.0396
 (MJ/min)
Calculated Pout  psia      350.0000
Head  ft                  1010.7957
Vol. flow rate              10.3242
 (ft3/min)
Mass flow rate  lb/min     492.7206
```

L-104 A/B: Atmospheric Reflux

```
Pump Summary

Equip. No.                    92
       Name
Output pressure  psia       18.0000
Efficiency                   0.6500
Calculated Pout  psia       18.0000
Vol. flow rate               8.0420
 (ft3/min)
Mass flow rate  lb/min     374.6806
```

L-105 A/B: Atmospheric Bottoms

```
Pump Summary

Equip. No.                    93
       Name
Output pressure  psia       20.0000
Efficiency                   0.6500
Calculated power             0.0484
 (MJ/min)
Calculated Pout  psia       20.0000
Head  ft                    17.6261
Vol. flow rate              40.2334
 (ft3/min)
Mass flow rate  lb/min    1314.7838
```

L-106 A/B: Vacuum Column Bottoms

```
Pump Summary

Equip. No.                    95
       Name
Output pressure  psia       25.0000
Efficiency                   0.6500
Calculated power             0.0454
 (MJ/min)
Calculated Pout  psia       25.0000
Head  ft                    35.2290
Vol. flow rate              15.0982
 (ft3/min)
```

```
Mass flow rate  lb/min     617.1440
```

L-107 A/B: Vacuum Bottoms

```
  Pump Summary

Equip. No.                      96
       Name
Output pressure  psia       18.0000
Efficiency                   0.6500
Calculated power             0.0353
 (MJ/min)
Calculated Pout  psia       18.0000
Head  ft                    10.3308
Vol. flow rate              39.1469
 (ft3/min)
Mass flow rate  lb/min    1637.0004
```

L-108 A/B: Vacuum Reflux

```
    Pump Summary


Equip. No.                      94
       Name
Output pressure  psia       20.0000
Efficiency                   0.6500
Calculated power             0.0802
 (MJ/min)
Calculated Pout  psia       20.0000
Head  ft                    55.1007
Vol. flow rate              16.6846
 (ft3/min)
Mass flow rate  lb/min     697.6542
```

L-109 A/B: Pre Diesel Decarbox

```
  Pump Summary

Equip. No.                      23
       Name
Output pressure  psia      350.0000
Efficiency                   0.6500
Calculated power             1.7352
 (MJ/min)
Calculated Pout  psia      350.0000
Head  ft                  1191.5531
Vol. flow rate              16.6846
 (ft3/min)
Mass flow rate  lb/min     697.6542
```

L-110 A/B: Jet Diesel Cut Heat Pump

```
Pump Summary
```

```
Equip. No.                       20
       Name
Output pressure  psia       30.0000
Efficiency                   0.6500
Calculated power             0.0682
 (MJ/min)
Calculated Pout  psia       30.0000
Head  ft                    50.7793
Vol. flow rate              15.1289
 (ft3/min)
Mass flow rate  lb/min     643.5379
```

L-111 A/B: Naphtha Product

```
Pump Summary

Equip. No.                       11
       Name
Output pressure  psia       25.0000
Efficiency                   0.6500
Calculated power             0.0147
 (MJ/min)
Calculated Pout  psia       25.0000
Head  ft                    25.2780
Vol. flow rate               7.0035
 (ft3/min)
Mass flow rate  lb/min     279.2748
```

L-112 A/B: Jet Diesel Cut Reflux

```
  Pump Summary

Equip. No.                       97
       Name
Output pressure  psia       19.0000
Efficiency                   0.6500
Calculated power             0.0042
 (MJ/min)
Calculated Pout  psia       19.0000
Head  ft                    12.2912
Vol. flow rate               3.4790
 (ft3/min)
Mass flow rate  lb/min     163.0358
```

L-113 A/B: Jet Diesel Cut Bottoms

```
Pump Summary

Equip. No.                       98
       Name
Output pressure  psia       25.0000
Efficiency                   0.6500
Calculated power             0.0316
 (MJ/min)
```

Calculated Pout	psia	25.0000
Head	ft	31.5233
Vol. flow rate (ft3/min)		13.1485
Mass flow rate	lb/min	480.5026

L-114 A/B: Diesel Fuel Oil Cut Reflux

Pump Summary

Equip. No.		99
Name		
Output pressure	psia	25.0000
Efficiency		0.6500
Calculated power (MJ/min)		0.0397
Calculated Pout	psia	25.0000
Head	ft	40.3419
Vol. flow rate (ft3/min)		13.2153
Mass flow rate	lb/min	471.7198

L-115 A/B: Diesel Fuel Oil Cut Bottoms

Pump Summary

Equip. No.		100
Name		
Output pressure	psia	40.0000
Efficiency		0.6500
Calculated power (MJ/min)		0.0019
Calculated Pout	psia	40.0000
Head	ft	104.1233
Vol. flow rate (ft3/min)		0.2761
Mass flow rate	lb/min	8.7821

L-116 A/B: Flash 5 Pump

Pump Summary

Equip. No.		69
Name		
Output pressure	psia	25.0000
Efficiency		0.6500
Calculated power (MJ/min)		0.0033
Calculated Pout	psia	25.0000
Head	ft	31.7573
Vol. flow rate (ft3/min)		1.0873
Mass flow rate	lb/min	49.3027

L-118 A/B: Jet Fuel Product

```
Pump Summary

Equip. No.                       13
       Name
Output pressure  psia       25.0000
Efficiency                   0.6500
Calculated power             0.0326
 (MJ/min)
Calculated Pout  psia       25.0000
Head  ft                    33.4219
Vol. flow rate               9.8557
 (ft3/min)
Mass flow rate  lb/min     467.1017
```

L-119 A/B: Naphtha Jet Reflux

```
Pump Summary

Equip. No.                      102
       Name
Output pressure  psia       19.0000
Efficiency                   0.6500
Calculated power             0.0010
 (MJ/min)
Calculated Pout  psia       19.0000
Head  ft                     3.3512
Vol. flow rate               3.3337
 (ft3/min)
Mass flow rate  lb/min     143.2450
```

L-120 A/B: Naphtha Jet Bottoms

```
Pump Summary

Equip. No.                      103
       Name
Output pressure  psia       28.0000
Efficiency                   0.6500
Calculated power             0.0071
 (MJ/min)
Calculated Pout  psia       28.0000
Head  ft                    11.2509
Vol. flow rate               7.9190
 (ft3/min)
Mass flow rate  lb/min     304.0661
```

L-121 A/B: Debutanizer Reflux

```
Pump Summary

Equip. No.                       36
       Name
```

```
Output pressure  psia      125.0000
Efficiency                   0.6500
Calculated power             0.0021
 (MJ/min)
Calculated Pout  psia      125.0000
Head  ft                    22.3090
Vol. flow rate               1.4094
 (ft3/min)
Mass flow rate  lb/min      45.4857
```

L-127 A/B: Syngas Reflux

```
  Pump Summary

Equip. No.                      38
       Name
Output pressure  psia      410.0000
Efficiency                   0.6500
Calculated power             0.0324
 (MJ/min)
Calculated Pout  psia      410.0000
Head  ft                    45.0664
Vol. flow rate              10.7761
 (ft3/min)
Mass flow rate  lb/min     344.3268
```

L-128 A/B: Flash 7 Pump

```
  Pump Summary

Equip. No.                      53
       Name
Output pressure  psia       20.0000
Efficiency                   0.6500
Calculated power             0.0151
 (MJ/min)
Calculated Pout  psia       20.0000
Head  ft                    16.4081
Vol. flow rate              10.0311
 (ft3/min)
Mass flow rate  lb/min     440.1758
```

L-129 A/B: Diesel Product

```
  Pump Summary

Equip. No.                      33
       Name
Output pressure  psia       25.0000
Efficiency                   0.6500
Calculated power             0.0177
 (MJ/min)
Calculated Pout  psia       25.0000
Head  ft                    17.9442
Vol. flow rate               9.7970
```

```
 (ft3/min)
Mass flow rate  lb/min     471.7198
```

L-130 A/B: Fuel Oil Pump

```
Pump Summary

Equip. No.                       54
       Name
Output pressure  psia       20.0000
Efficiency                   0.6500
Calculated power             0.0475
 (MJ/min)
Calculated Pout  psia       20.0000
Head  ft                    56.7149
Vol. flow rate               8.3134
 (ft3/min)
Mass flow rate  lb/min     401.0499
```

H.2. Fatty Acid Recovery Design

H.2.i. Distillation Columns

D-701: Atmospheric Column

```
TOWR Rigorous Distillation Summary

Equip. No.                       14
       Name
No. of stages                     7
1st feed stage                    5
Condenser mode                    7
Condenser spec.              0.5000
Cond comp i                      18
Reboiler mode                     7
Reboiler spec.               0.9900
Reboiler comp i                  94
Initial flag                      1
Calc cond duty  MJ/min     -93.6269
Calc rebr duty  MJ/min     326.5201
Est. Dist. rate              5.5732
 (lbmol/min)
Est. Reflux rate             5.2486
 (lbmol/min)
Est. T top  F              211.6549
Est. T bottom  F           711.7022
Est. T 2  F                493.2700
Tray type                         3
Column diameter  ft          7.0000
Tray space  ft               2.0000
Thickness (top)  ft          0.0052
Thickness (bot)  ft          0.0052
No of sections                    1
Calc Reflux ratio            0.0969
Calc Reflux mole             0.2236
```

```
 (lbmol/min)
Calc Reflux mass           28.6876
 (lb/min)
No of passes (S1)             1
Weir side width  ft         1.2708
Weir height  ft             0.1667
System factor               1.0000
Optimization flag             1
```

D-702: Vacuum Column

```
TOWR Rigorous Distillation Summary

Equip. No.                   51
       Name
No. of stages                20
1st feed stage               10
Top pressure  psia          4.0000
Condenser mode                7
Condenser spec.             0.9000
Cond comp i                  26
Reboiler mode                 7
Reboiler spec.              0.9900
Reboiler comp i              29
Initial flag                  6
Calc cond duty  MJ/min    -147.1778
Calc rebr duty  MJ/min      91.6576
Est. Dist. rate             2.4623
 (lbmol/min)
Est. Reflux rate            2.4031
 (lbmol/min)
Est. T top  F             462.3700
Est. T bottom  F          671.9116
Est. T 2  F               507.0500
Tray type                     3
Column diameter  ft         7.0000
Tray space  ft              2.0000
No of sections                1
Bottom Pout  psia           6.0000
Calc Reflux ratio           0.6386
Calc Reflux mole            1.5048
 (lbmol/min)
Calc Reflux mass          353.7715
 (lb/min)
No of passes (S1)             1
Weir side width  ft         1.2708
Weir height  ft             0.1667
System factor               1.0000
Optimization flag             1
```

D-703: Water Removal Column

```
    Shortcut Distillation Summary

Equip. No.                  138
```

Name	
Mode	2
Light key component	2.0000
Light key split	0.9500
Heavy key component	83.0000
Heavy key split	0.0100
R/Rmin	1.4000
Number of stages	18.7198
Min. No. of stages	8.8267
Feed stage	11.7027
Condenser duty MJ/min	-2582.9512
Reboiler duty MJ/min	2690.1323
Colm pressure psia	10.0000
Reflux ratio, minimum	0.5586
Calc. Reflux ratio	0.7820

D-704: C2-C4 Split Column

TOWR Rigorous Distillation Summary

Equip. No.	48
Name	
No. of stages	20
1st feed stage	16
Top pressure psia	2.0000
Condenser mode	7
Condenser spec.	0.9900
Cond comp i	83
Reboiler mode	7
Reboiler spec.	0.9900
Reboiler comp i	85
Initial flag	1
Calc cond duty MJ/min	-263.0106
Calc rebr duty MJ/min	279.1794
Est. Dist. rate (lbmol/min)	3.9495
Est. Reflux rate (lbmol/min)	3.1878
Est. T top F	183.7900
Est. T bottom F	439.1642
Est. T 2 F	184.3324
Tray type	3
Column diameter ft	8.0000
Tray space ft	2.0000
No of sections	1
Calc Reflux ratio	2.4107
Calc Reflux mole (lbmol/min)	9.5574
Calc Reflux mass (lb/min)	192.6024
No of passes (S1)	1
Weir side width ft	1.4583
Weir height ft	0.1667
System factor	1.0000
Optimization flag	1

D-705: Acetic Acid Column

Shortcut Distillation Summary

Equip. No.	42
Name	
Mode	2
Light key component	83.0000
Light key split	0.9900
Heavy key component	85.0000
Heavy key split	0.0100
R/Rmin	1.4000
Number of stages	53.4196
Min. No. of stages	22.0560
Feed stage	27.2098
Condenser duty MJ/min	-100.8374
Reboiler duty MJ/min	115.9022
Colm pressure psia	2.0000
Reflux ratio, minimum	0.2244
Calc. Reflux ratio	0.3141

D-706: C6-C7 Split Column

TOWR Rigorous Distillation Summary

Equip. No.	24
Name	
No. of stages	35
1st feed stage	15
Condenser mode	7
Condenser spec.	0.9800
Cond comp i	87
Reboiler mode	7
Reboiler spec.	0.9950
Reboiler comp i	88
Initial flag	6
Calc cond duty MJ/min	-28.9264
Calc rebr duty MJ/min	60.6265
Est. Dist. rate (lbmol/min)	0.2170
Est. Reflux rate (lbmol/min)	0.3407
Est. T top F	365.9845
Est. T bottom F	506.7945
Est. T 2 F	383.0354
Tray type	3
Column diameter ft	3.5000
Tray space ft	2.0000
Thickness (top) ft	0.0052
Thickness (bot) ft	0.0547
No of sections	1
Calc Reflux ratio	4.7940
Calc Reflux mole (lbmol/min)	1.0301
Calc Reflux mass (lb/min)	108.3060

No of passes (S1)	1
Weir side width ft	0.6458
Weir height ft	0.1667
System factor	1.0000
Optimization flag	1

D-707: C4-C5 Split Column

TOWR Rigorous Distillation Summary

Equip. No.	19
Name	
No. of stages	32
1st feed stage	12
Top pressure psia	6.0000
Condenser mode	7
Condenser spec.	0.9900
Cond comp i	85
Reboiler mode	7
Reboiler spec.	0.9970
Reboiler comp i	86
Initial flag	1
Calc cond duty MJ/min	-5.5801
Calc rebr duty MJ/min	7.3175
Est. Dist. rate (lbmol/min)	0.0097
Est. Reflux rate (lbmol/min)	0.1714
Est. T top F	184.4294
Est. T bottom F	347.2296
Est. T 2 F	191.9109
Tray type	3
Column diameter ft	1.5000
Tray space ft	2.0000
No of sections	1
Calc Reflux ratio	4.8940
Calc Reflux mole (lbmol/min)	0.2124
Calc Reflux mass (lb/min)	17.4151
No of passes (S1)	1
Weir side width ft	0.2708
Weir height ft	0.1667
System factor	1.0000
Optimization flag	1

D-708: C3-C4 Product Column

TOWR Rigorous Distillation Summary

Equip. No.	23
Name	
No. of stages	28
1st feed stage	15
Condenser mode	7

```
Condenser spec.                 0.9950
Cond comp i                       84
Reboiler mode                      7
Reboiler spec.                  0.9950
Reboiler comp i                   85
Initial flag                       1
Calc cond duty  MJ/min         -3.3919
Calc rebr duty  MJ/min          3.4266
Est. Dist. rate                 0.0053
 (lbmol/min)
Est. Reflux rate                0.0646
 (lbmol/min)
Est. T top  F                 214.8425
Est. T bottom  F              213.8652
Est. T 2  F                   216.1380
Tray type                          3
Column diameter  ft             1.0000
Tray space  ft                  2.0000
No of sections                     1
Calc Reflux ratio               9.3363
Calc Reflux mole                0.1535
 (lbmol/min)
Calc Reflux mass               11.2810
 (lb/min)
No of passes (S1)                  1
Weir side width  ft             0.1458
Weir height  ft                 0.1667
System factor                   1.0000
Optimization flag                  1
```

D-709: C5-C6 Product Column

```
TOWR Rigorous Distillation Summary

Equip. No.                        18
       Name
No. of stages                     30
1st feed stage                    15
Top pressure  psia             14.0000
Condenser mode                     7
Condenser spec.                 0.9900
Cond comp i                       86
Reboiler mode                      7
Reboiler spec.                  0.9930
Reboiler comp i                   87
Initial flag                       6
Calc cond duty  MJ/min        -12.9701
Calc rebr duty  MJ/min         13.6273
Est. Dist. rate                 0.0647
 (lbmol/min)
Est. Reflux rate                0.4562
 (lbmol/min)
Est. T top  F                 363.5481
Est. T bottom  F              399.2157
Est. T 2  F                   363.8499
Tray type                          3
```

Column diameter ft	1.5000
Tray space ft	2.0000
No of sections	1
Calc Reflux ratio	8.1560
Calc Reflux mole (lbmol/min)	0.5228
Calc Reflux mass (lb/min)	53.4548
No of passes (S1)	1
Weir side width ft	0.2708
Weir height ft	0.1667
System factor	1.0000
Optimization flag	1

D-710: C8-C9 Split Column

TOWR Rigorous Distillation Summary

Equip. No.	25
Name	
No. of stages	26
1st feed stage	15
Top pressure psia	6.0000
Condenser mode	7
Condenser spec.	0.9900
Cond comp i	89
Reboiler mode	7
Reboiler spec.	0.9900
Reboiler comp i	90
Initial flag	6
Calc cond duty MJ/min	-78.4148
Calc rebr duty MJ/min	91.0365
Est. Dist. rate (lbmol/min)	0.4158
Est. Reflux rate (lbmol/min)	1.5386
Est. T top F	388.6624
Est. T bottom F	497.0000
Est. T 2 F	392.3128
Tray type	3
Column diameter ft	5.0000
Tray space ft	2.0000
No of sections	1
Calc Reflux ratio	6.3058
Calc Reflux mole (lbmol/min)	2.6344
Calc Reflux mass (lb/min)	357.6712
No of passes (S1)	1
Weir side width ft	0.8958
Weir height ft	0.1667
System factor	1.0000
Optimization flag	1

D-711: C7-C8 Product Column

```
TOWR Rigorous Distillation Summary

Equip. No.                      27
       Name
No. of stages                   28
1st feed stage                  15
Top pressure  psia            6.0000
Condenser mode                   7
Condenser spec.               0.9900
Cond comp i                     88
Reboiler mode                    7
Reboiler spec.                0.9900
Reboiler comp i                 89
Initial flag                     6
Calc cond duty  MJ/min      -36.4806
Calc rebr duty  MJ/min       36.5452
Est. Dist. rate               0.2515
 (lbmol/min)
Est. Reflux rate              0.6371
 (lbmol/min)
Est. T top  F               378.7951
Est. T bottom  F            407.5324
Est. T 2  F                 378.9779
Tray type                        3
Column diameter  ft           3.5000
Tray space  ft                2.0000
No of sections                   1
Calc Reflux ratio             4.7927
Calc Reflux mole              1.1994
 (lbmol/min)
Calc Reflux mass            156.1142
 (lb/min)
No of passes (S1)                1
Weir side width  ft           0.6458
Weir height  ft               0.1667
System factor                 1.0000
Optimization flag                1
```

D-712: C10-C11 Split Column

```
                      TOWR Rigorous Distillation Summary

Equip. No.                      36
       Name
No. of stages                   32
1st feed stage                  19
Top pressure  psia            4.0000
Condenser mode                   7
Condenser spec.               0.9930
Cond comp i                     91
Reboiler mode                    7
Reboiler spec.                0.9900
Reboiler comp i                 92
Initial flag                     6
```

```
Calc cond duty  MJ/min     -63.1096
Calc rebr duty  MJ/min      67.3066
Est. Dist. rate              0.3120
 (lbmol/min)
Est. Reflux rate             0.7858
 (lbmol/min)
Est. T top  F              421.2649
Est. T bottom  F           533.0551
Est. T 2  F                424.2773
Column diameter  ft          4.5000
Tray space  ft               2.0000
No of sections                  1
Calc Reflux ratio            6.2691
Calc Reflux mole             1.9774
 (lbmol/min)
Calc Reflux mass           325.6507
 (lb/min)
No of passes (S1)               1
Weir side width  ft          0.3958
Weir height  ft              0.1667
System factor                1.0000
Optimization flag               1
```

D-713: C9-C10 Product Column

```
TOWR Rigorous Distillation Summary

Equip. No.                    127
       Name
No. of stages                  32
1st feed stage                 17
Top pressure  psia           4.0000
Condenser mode                  7
Condenser spec.              0.9900
Cond comp i                    90
Reboiler mode                   7
Reboiler spec.               0.9920
Reboiler comp i                91
Initial flag                    6
Calc cond duty  MJ/min     -31.3174
Calc rebr duty  MJ/min      31.3667
Est. Dist. rate              0.1698
 (lbmol/min)
Est. Reflux rate             1.0689
 (lbmol/min)
Est. T top  F              410.7625
Est. T bottom  F           436.3393
Est. T 2  F                410.9720
Tray type                       3
Column diameter  ft          3.5000
Tray space  ft               2.0000
No of sections                  1
Calc Reflux ratio            5.8857
Calc Reflux mole             0.9941
 (lbmol/min)
Calc Reflux mass           157.2656
```

```
 (lb/min)
No of passes (S1)              1
Weir side width  ft       0.6458
Weir height  ft           0.1667
System factor             1.0000
Optimization flag              1
```

D-714: C11 Product Column

```
TOWR Rigorous Distillation Summary

Equip. No.                    40
       Name
No. of stages                 30
1st feed stage                17
Top pressure  psia        2.0000
Condenser mode                 7
Condenser spec.           0.9900
Cond comp i                   92
Reboiler mode                  7
Reboiler spec.            0.9900
Reboiler comp i               93
Initial flag                   6
Calc cond duty  MJ/min  -20.6277
Calc rebr duty  MJ/min   26.9035
Est. Dist. rate           0.0560
 (lbmol/min)
Est. Reflux rate          0.0561
 (lbmol/min)
Est. T top  F           419.7954
Est. T bottom  F        507.3910
Est. T 2  F             420.0214
Tray type                      3
Column diameter  ft       3.5000
Tray space  ft            2.0000
No of sections                 1
Calc Reflux ratio        11.4354
Calc Reflux mole          0.6449
 (lbmol/min)
Calc Reflux mass        120.0440
 (lb/min)
No of passes (S1)              1
Weir side width  ft       0.6458
Weir height  ft           0.1667
System factor             1.0000
Optimization flag              1
```

D-715: Hexane Splitter Column

```
TOWR Rigorous Distillation Summary

Equip. No.                    29
       Name
No. of stages                  8
1st feed stage                 4
```

```
Condenser type                    1
Condenser mode                    7
Condenser spec.              0.6000
Cond comp i                      10
Reboiler mode                     7
Reboiler spec.               0.9900
Reboiler comp i                  11
Initial flag                      1
Calc cond duty  MJ/min      -4.6730
Calc rebr duty  MJ/min      50.9941
Est. Dist. rate              2.7120
 (lbmol/min)
Est. Reflux rate             2.3699
 (lbmol/min)
Est. T top  F              123.8975
Est. T bottom  F           352.3092
Est. T 2  F                 48.4705
Tray type                         3
Column diameter  ft          3.0000
Tray space  ft               2.0000
Thickness (top)  ft          0.0052
Thickness (bot)  ft          0.0104
No of sections                    1
Calc Reflux ratio            1.5408
Calc Reflux mole             0.3771
 (lbmol/min)
Calc Reflux mass            25.8028
 (lb/min)
No of passes (S1)                 1
Weir side width  ft          0.5833
Weir height  ft              0.1667
System factor                1.0000
Optimization flag                 1
```

D-716: Naphtha Jet Cut Column

```
TOWR Rigorous Distillation Summary

Equip. No.                       28
       Name
No. of stages                    30
1st feed stage                    7
Top pressure  psia          18.0000
Cond pressure drop           5.0000
 (psi)
Colm pressure drop           5.0000
 (psi)
Condenser mode                    1
Condenser spec.              1.2500
Cond comp i                      14
Reboiler mode                     7
Reboiler spec.               0.9965
Reboiler comp i                  73
Initial flag                      6
Calc cond duty  MJ/min     -39.5990
Calc rebr duty  MJ/min      54.6560
```

```
Est. Dist. rate              1.5617
 (lbmol/min)
Est. Reflux rate             1.9521
 (lbmol/min)
Est. T top  F              208.5920
Est. T bottom  F           419.4886
Est. T 2  F                243.7305
Tray type                      3
Column diameter  ft          3.5000
Tray space  ft               2.0000
Thickness (top)  ft          0.0052
Thickness (bot)  ft          0.0417
No of sections                 1
Calc Reflux ratio            1.2500
Calc Reflux mole             1.3822
 (lbmol/min)
Calc Reflux mass           129.3706
 (lb/min)
No of passes (S1)              1
Weir side width  ft          0.6458
Weir height  ft              0.1667
System factor                1.0000
Optimization flag              1
```

D-717: Jet Diesel Cut Column

```
TOWR Rigorous Distillation Summary

Equip. No.                      26
       Name
No. of stages                   25
1st feed stage                  13
Top pressure  psia         15.0000
Condenser mode                   7
Condenser spec.             0.2500
Cond comp i                     20
Reboiler mode                    7
Reboiler spec.              0.9990
Reboiler comp i                 21
Initial flag                     1
Calc cond duty  MJ/min   -100.9780
Calc rebr duty  MJ/min    174.9857
Est. Dist. rate             2.6149
 (lbmol/min)
Est. Reflux rate            5.0238
 (lbmol/min)
Est. T top  F             100.0000
Est. T bottom  F          654.9268
Est. T 2  F               517.7233
Tray type                        3
Column diameter  ft         7.5000
Tray space  ft              2.0000
Thickness (top)  ft         0.0052
Thickness (bot)  ft         0.0130
No of sections                   1
Bottom Pout  psia          25.0000
```

```
Calc Reflux ratio            4.5986
Calc Reflux mole             3.4270
 (lbmol/min)
Calc Reflux mass           626.5112
 (lb/min)
No of passes (S1)              1
Weir side width  ft          1.3333
Weir height  ft              0.1667
System factor                1.0000
Optimization flag              1
```

D-718: Diesel Fuel Oil Cut Column

```
TOWR Rigorous Distillation Summary

Equip. No.                    34
       Name
No. of stages                 50
1st feed stage                23
Condenser mode                 7
Condenser spec.              0.9500
Cond comp i                   27
Reboiler mode                  7
Reboiler spec.               0.9700
Reboiler comp i               29
Initial flag                   1
Calc cond duty  MJ/min     -84.7927
Calc rebr duty  MJ/min     105.0830
Est. Dist. rate              3.0575
 (lbmol/min)
Est. Reflux rate             7.6994
 (lbmol/min)
Est. T top  F              603.0223
Est. T bottom  F           883.3350
Est. T 2  F                625.3803
Tray type                      3
Column diameter  ft          6.5000
Tray space  ft               2.0000
Thickness (top)  ft          0.0078
Thickness (bot)  ft          0.0521
No of sections                 1
Calc Reflux ratio            0.4555
Calc Reflux mole             0.9667
 (lbmol/min)
Calc Reflux mass           239.0129
 (lb/min)
No of passes (S1)              1
Weir side width  ft          1.2083
Weir height  ft              0.1667
System factor                1.0000
Optimization flag              1
```

D-719: Syngas Column

```
TOWR Rigorous Distillation Summary
```

```
Equip. No.                       61
       Name
No. of stages                    40
1st feed stage                   15
Top pressure  psia         470.0000
Condenser type                    1
Condenser mode                    7
Condenser spec.              0.9700
Cond comp i                       8
Reboiler mode                     7
Reboiler spec.               0.9800
Reboiler comp i                   9
Initial flag                      1
Calc cond duty  MJ/min     -18.6017
Calc rebr duty  MJ/min      35.0872
Est. Dist. rate              8.6145
 (lbmol/min)
Est. Reflux rate             0.1847
 (lbmol/min)
Est. T top  F               13.6180
Est. T bottom  F           366.0512
Tray type                         3
Column diameter  ft          7.5000
Tray space  ft               2.0000
Thickness (top)  ft          0.1563
Thickness (bot)  ft          0.1563
No of sections                    1
Calc Reflux ratio            0.3064
Calc Reflux mole             2.6250
 (lbmol/min)
Calc Reflux mass           107.7711
 (lb/min)
No of passes (S1)                 1
Weir side width  ft          1.3333
Weir height  ft              0.1667
System factor                1.0000
Optimization flag                 1
```

D-720: Debutanizer Column

```
TOWR Rigorous Distillation Summary

Equip. No.                        6
       Name
No. of stages                    12
1st feed stage                    8
Top pressure  psia         120.0000
Condenser mode                    7
Condenser spec.              0.9500
Cond comp i                       9
Reboiler mode                     7
Reboiler spec.               0.9700
Reboiler comp i                  10
Initial flag                      6
Calc cond duty  MJ/min     -40.0474
```

Calc rebr duty MJ/min	38.3893
Est. Dist. rate (lbmol/min)	0.7358
Est. Reflux rate (lbmol/min)	2.4857
Est. T top F	152.6343
Est. T bottom F	270.8360
Est. T 2 F	156.5625
Tray type	3
Column diameter ft	2.5000
Tray space ft	2.0000
Thickness (top) ft	0.0156
Thickness (bot) ft	0.0156
No of sections	1
Calc Reflux ratio	5.5467
Calc Reflux mole (lbmol/min)	4.1037
Calc Reflux mass (lb/min)	235.3021
No of passes (S1)	1
Weir side width ft	0.4583
Weir height ft	0.1667
System factor	1.0000
Optimization flag	1

H.2.ii. Flash Drums

D-601: Flash 1

Flash Summary

Equip. No.	7
Name	
Flash Mode	6
Param 1	100.0000
Heat duty MJ/min	-1.1231
Type	1
Diameter ft	4.5000
Length ft	18.8831
Vessel thickness ft	0.0313
Head thickness ft	0.0313
Straight flange ft	0.1667
Metal density lb/ft3	489.0240

K values:	
triolein	0.024
Water	23.084
Hydrogen	85.813
Carbon Monoxide	71.026
Carbon Dioxide	31.460
Methane	47.577
Ethane	19.666
n-Propane	11.531
N-Butane	6.781
N-Pentane	4.112
N-Hexane	2.515

N-Heptane	1.590
N-Octane	1.005
N-Nonane	0.637
N-Decane	0.410
N-Undecane	0.266
N-Dodecane	0.172
N-Tridecane	0.113
N-Tetradecane	0.074
N-Pentadecane	0.049
N-Hexadecane	0.031
N-Heptadecane	0.022
N-Octadecane	0.016
N-Nonadecane	0.011
Eicosane	7.602E-003
uneicosane	4.857E-003
n-docosane	3.508E-003
n-tricosane	2.333E-003
n-Tetracosane	1.626E-003
n-pentacosane	1.166E-003
n-hexacosane	8.134E-004

EQUIPMENT SUMMARIES

N-Heptacosane	5.439E-004
n-Octacosane	4.229E-004
n-Nonacosane	3.231E-004
n-triacontane	2.343E-004
n-Dotriacontane	1.336E-004
n-Hexatriaconta	4.449E-005
2-Methyloctane	0.728
Cyclopentene	3.718
Methylcyclopent	2.336
Ethylcyclopenta	1.409
N-Propylcyclope	0.855
n-Butylcyclopen	0.562
N-Butylcyclohex	0.339
N-Hexylcyclo-C5	0.224
N-Octylcyclo-C5	0.095
N-Nonylcyclopen	0.061
N-Decylcyclopen	0.040
N-Decylcyclohex	0.025
N-Dodecylcyclop	0.019
N-Tridecylcyclo	0.013
Ethylene	23.352
Propylene	12.391
1-Butene	7.338
1-Pentene	4.476
1-Hexene	2.690
1-Heptene	1.696
1-Octene	1.067
1-Nonene	0.676
1-Decene	0.435
1-Undecene	0.282
1-Dodecene	0.183

1-Tridecene	0.120
1-Tetradecene	0.079
1-Pentadecene	0.052
1-Hexadecene	0.035
1-Heptadecene	0.024
1-Octadecene	0.016
1-Nonadecene	0.011
1-Eicosene	7.163E-003
Toluene	1.362
Ethylbenzene	0.863
N-Propylbenzene	0.560
1-butylbenzene	0.351
N-Pentylbenzene	0.222
N-Hexylbenzene	0.143
N-Heptylbenzene	0.091
N-Octylbenzene	0.059
N-Nonylbenzene	0.038

EQUIPMENT SUMMARIES

N-Dodecylbenzen	0.011
N-Decylbenzene	0.026
N-Undecylbenzen	0.017
Acetic Acid	1.802
Propionic Acid	1.142
N-Butyric Acid	0.739
Pentanoic Acid	0.439
N-Hexanoic Acid	0.281
Heptanoic Acid	0.183
N-Octanoic Acid	0.117
N-Nonanoic Acid	0.075
N-Decanoic Acid	0.048
undecanoic acid	0.033
Dodecanoic Acid	0.022
N-Tridecanoic A	0.015
N-Tetradecanoic	0.010
Pentadecanoic A	7.053E-003
N-Hexadecanoic	4.894E-003
Heptadecanoic A	3.442E-003
n-Octadecanoic	2.324E-003
Carbon	2.012E-008
Nitrogen	71.884
N-Heptylcyclope	0.143
Perylene	9.131E-004
pentacontane	7.827E-006
dopentacontane	6.030E-006
octatetracontan	1.003E-005
hexatetracontan	1.390E-005
tetratetraconta	1.957E-005
dotetracontane	2.488E-005
tetracontane	4.290E-005
octatriacontane	7.461E-005
tetratriacontan	2.226E-004
2-methyltetrade	0.061

Linolenic Acid	3.060E-003
Linoleic Acid	3.431E-003
Oleic Acid	2.818E-003
Benzene	2.281
O-Xylene	0.771
M-Xylene	0.827
P-Xylene	0.830
Indan	0.455
1-Methylindene	0.291
Naphthalene	0.238
1-Methylnaphtha	0.136
1-propylnaphtha	0.064
2,6-Dimethylnap	0.085
Sulfolane	0.097

Varsol	0.233

D-602: Flash 2

Flash Summary

Equip. No.	8
Name	
Flash Mode	6
Param 1	20.0000
Heat duty MJ/min	-0.8991
Type	1
Diameter ft	4.5000
Length ft	17.5812
Vessel thickness ft	0.0208
Head thickness ft	0.0208
Straight flange ft	0.1667
Metal density lb/ft3	489.0240

K values:	
triolein	1.120
Water	84.533
Hydrogen	570.651
Carbon Monoxide	402.815
Carbon Dioxide	132.945
Methane	247.357
Ethane	73.932
n-Propane	35.844
N-Butane	17.452
N-Pentane	8.821
N-Hexane	4.527
N-Heptane	2.395
N-Octane	1.272
N-Nonane	0.676
N-Decane	0.369
N-Undecane	0.204

N-Dodecane	0.112
N-Tridecane	0.062
N-Tetradecane	0.034
N-Pentadecane	0.020
N-Hexadecane	0.011
N-Heptadecane	6.508E-003
N-Octadecane	4.194E-003
N-Nonadecane	2.695E-003
Eicosane	1.503E-003
uneicosane	7.866E-004
n-docosane	5.035E-004
n-tricosane	2.811E-004
n-Tetracosane	1.687E-004
n-pentacosane	1.063E-004
n-hexacosane	6.368E-005

EQUIPMENT SUMMARIES

N-Heptacosane	3.558E-005
n-Octacosane	2.529E-005
n-Nonacosane	1.744E-005
n-triacontane	1.108E-005
n-Dotriacontane	5.067E-006
n-Hexatriaconta	1.077E-006
2-Methyloctane	0.825
Cyclopentene	7.926
Methylcyclopent	4.253
Ethylcyclopenta	2.146
N-Propylcyclope	1.127
n-Butylcyclopen	0.605
N-Butylcyclohex	0.343
N-Hexylcyclo-C5	0.170
N-Octylcyclo-C5	0.052
N-Nonylcyclopen	0.028
N-Decylcyclopen	0.016
N-Decylcyclohex	8.523E-003
N-Dodecylcyclop	5.597E-003
N-Tridecylcyclo	3.427E-003
Ethylene	93.049
Propylene	39.525
1-Butene	19.423
1-Pentene	9.578
1-Hexene	4.930
1-Heptene	2.641
1-Octene	1.402
1-Nonene	0.751
1-Decene	0.408
1-Undecene	0.222
1-Dodecene	0.121
1-Tridecene	0.068
1-Tetradecene	0.038
1-Pentadecene	0.021
1-Hexadecene	0.012
1-Heptadecene	7.238E-003

1-Octadecene	4.200E-003
1-Nonadecene	2.345E-003
1-Eicosene	1.368E-003
Toluene	2.044
Ethylbenzene	1.101
N-Propylbenzene	0.610
1-butylbenzene	0.321
N-Pentylbenzene	0.171
N-Hexylbenzene	0.093
N-Heptylbenzene	0.050
N-Octylbenzene	0.027
N-Nonylbenzene	0.015

EQUIPMENT SUMMARIES

N-Dodecylbenzen	2.778E-003
N-Decylbenzene	8.361E-003
N-Undecylbenzen	4.538E-003
Acetic Acid	2.625
Propionic Acid	1.341
N-Butyric Acid	0.704
Pentanoic Acid	0.346
N-Hexanoic Acid	0.186
Heptanoic Acid	0.104
N-Octanoic Acid	0.057
N-Nonanoic Acid	0.032
N-Decanoic Acid	0.017
undecanoic acid	0.010
Dodecanoic Acid	5.779E-003
N-Tridecanoic A	3.122E-003
N-Tetradecanoic	1.970E-003
Pentadecanoic A	1.197E-003
N-Hexadecanoic	6.775E-004
Heptadecanoic A	4.256E-004
n-Octadecanoic	2.626E-004
Carbon	7.597E-011
Nitrogen	419.381
N-Heptylcyclope	0.092
Perylene	1.154E-004
pentacontane	1.889E-007
dopentacontane	1.372E-007
octatetracontan	2.552E-007
hexatetracontan	3.870E-007
tetratetraconta	5.973E-007
dotetracontane	7.844E-007
tetracontane	1.671E-006
octatriacontane	3.586E-006
tetratriacontan	1.601E-005
2-methyltetrade	0.028
Linolenic Acid	3.283E-004
Linoleic Acid	3.847E-004
Oleic Acid	2.942E-004
Benzene	4.137
O-Xylene	0.944

M-Xylene	1.024
P-Xylene	1.033
Indan	0.473
1-Methylindene	0.260
Naphthalene	0.203
1-Methylnaphtha	0.095
1-propylnaphtha	0.033
2,6-Dimethylnap	0.049
Sulfolane	0.059

Varsol	0.173

D-603: Flash 3

Flash Summary

Equip. No.	46
Name	
Flash Mode	6
Param 1	15.0000
Heat duty MJ/min	-5.8675
Type	1
Diameter ft	4.0000
Length ft	6.2743
Vessel thickness ft	0.0208
Head thickness ft	0.0208
Straight flange ft	0.1667
Metal density lb/ft3	489.0240

K values:

triolein	1.765E+012
Water	20.656
Hydrogen	1343.646
Carbon Monoxide	621.438
Carbon Dioxide	65.483
Methane	214.979
Ethane	29.572
n-Propane	7.751
N-Butane	2.059
N-Pentane	0.595
N-Hexane	0.176
N-Heptane	0.053
N-Octane	0.017
N-Nonane	5.160E-003
N-Decane	1.770E-003
N-Undecane	5.891E-004
N-Dodecane	2.033E-004
N-Tridecane	6.532E-005
N-Tetradecane	2.255E-005
N-Pentadecane	8.276E-006
N-Hexadecane	2.980E-006

N-Heptadecane	1.308E-006
N-Octadecane	6.457E-007
N-Nonadecane	3.169E-007
Eicosane	1.020E-007
uneicosane	2.854E-008
n-docosane	1.375E-008
n-tricosane	4.531E-009
n-Tetracosane	1.800E-009
n-pentacosane	7.928E-010
n-hexacosane	3.172E-010

EQUIPMENT SUMMARIES

N-Heptacosane	1.011E-010
n-Octacosane	6.146E-011
n-Nonacosane	3.331E-011
n-triacontane	1.498E-011
n-Dotriacontane	4.188E-012
n-Hexatriaconta	2.855E-013
2-Methyloctane	8.044E-003
Cyclopentene	0.463
Methylcyclopent	0.160
Ethylcyclopenta	0.047
N-Propylcyclope	0.017
n-Butylcyclopen	4.546E-003
N-Butylcyclohex	2.666E-003
N-Hexylcyclo-C5	4.680E-004
N-Octylcyclo-C5	5.827E-005
N-Nonylcyclopen	1.949E-005
N-Decylcyclopen	7.425E-006
N-Decylcyclohex	1.987E-006
N-Dodecylcyclop	1.454E-006
N-Tridecylcyclo	6.918E-007
Ethylene	44.695
Propylene	9.019
1-Butene	2.459
1-Pentene	0.589
1-Hexene	0.198
1-Heptene	0.065
1-Octene	0.021
1-Nonene	6.788E-003
1-Decene	2.181E-003
1-Undecene	6.875E-004
1-Dodecene	2.105E-004
1-Tridecene	7.844E-005
1-Tetradecene	2.783E-005
1-Pentadecene	9.842E-006
1-Hexadecene	3.613E-006
1-Heptadecene	1.472E-006
1-Octadecene	5.492E-007
1-Nonadecene	1.857E-007
1-Eicosene	7.113E-008
Toluene	0.038
Ethylbenzene	0.012

N-Propylbenzene	4.289E-003
1-butylbenzene	1.299E-003
N-Pentylbenzene	4.145E-004
N-Hexylbenzene	1.393E-004
N-Heptylbenzene	4.385E-005
N-Octylbenzene	1.481E-005
N-Nonylbenzene	4.225E-006

Simulation: NCP of TAG oils Purificatio Date: 05/10/2017 Time: 12:12:08

EQUIPMENT SUMMARIES

N-Dodecylbenzen	2.372E-007
N-Decylbenzene	1.522E-006
N-Undecylbenzen	4.611E-007
Acetic Acid	0.032
Propionic Acid	7.715E-003
N-Butyric Acid	1.906E-003
Pentanoic Acid	5.191E-004
N-Hexanoic Acid	1.555E-004
Heptanoic Acid	5.308E-005
N-Octanoic Acid	1.828E-005
N-Nonanoic Acid	6.805E-006
N-Decanoic Acid	2.282E-006
undecanoic acid	8.560E-007
Dodecanoic Acid	3.048E-007
N-Tridecanoic A	7.216E-008
N-Tetradecanoic	4.532E-008
Pentadecanoic A	1.930E-008
N-Hexadecanoic	5.300E-009
Heptadecanoic A	2.575E-009
n-Octadecanoic	1.421E-009
Carbon	1.000E-020
Nitrogen	724.492
N-Heptylcyclope	1.646E-004
Perylene	9.937E-010
pentacontane	3.642E-013
dopentacontane	2.705E-013
octatetracontan	4.642E-013
hexatetracontan	7.829E-013
tetratetraconta	1.302E-012
dotetracontane	1.338E-012
tetracontane	5.610E-012
octatriacontane	2.298E-011
tetratriacontan	3.354E-010
2-methyltetrade	2.287E-005
Linolenic Acid	1.011E-009
Linoleic Acid	1.449E-009
Oleic Acid	8.917E-010
Benzene	0.142
O-Xylene	9.093E-003
M-Xylene	0.010
P-Xylene	0.011
Indan	2.576E-003
1-Methylindene	9.205E-004
Naphthalene	5.801E-004

1-Methylnaphtha	1.478E-004
1-propylnaphtha	1.866E-005
2,6-Dimethylnap	3.964E-005
Sulfolane	4.249E-005

Varsol	4.110E-004
Ethylene Glycol	4.212E-003
Air	435.453
Oxygen	319.986
Trimethylamine	1.772

D-604: Acetic Acid Separator 1

Three Phase Flash Summary

Equip. No.	39
Name	
Flash Mode	1
Param1	420.0000
Param2	200.0000
Heat duty MJ/min	-25.8485

D-605: Acetic Acid Separator 2

Three Phase Flash Summary

Equip. No.	65
Name	
Flash Mode	1
Param1	146.0000
Param2	30.0000
Heat duty MJ/min	18.7537

D-606: Flash 4

Flash Summary

Equip. No.	100
Name	
Flash Mode	6
Param 1	250.0000
Heat duty MJ/min	-0.3302
Type	1
Diameter ft	2.5000
Length ft	9.3197
Vessel thickness ft	0.0417
Head thickness ft	0.0417
Straight flange ft	0.1667
Metal density lb/ft3	489.0240

K values:

triolein	3.078E-011
Water	37.150
Hydrogen	5840.199
Carbon Monoxide	6207.206
Carbon Dioxide	5980.964
Methane	3196.064
Ethane	1577.522
n-Propane	1.260
N-Butane	5924.098
N-Pentane	0.719
N-Hexane	0.466
N-Heptane	0.300
N-Octane	0.188
N-Nonane	0.116
N-Decane	0.070
N-Undecane	0.043
N-Dodecane	0.026
N-Tridecane	0.016
N-Tetradecane	9.574E-003
N-Pentadecane	5.837E-003
N-Hexadecane	3.525E-003
N-Heptadecane	2.232E-003
N-Octadecane	1.326E-003
N-Nonadecane	8.412E-004
Eicosane	4.702E-004
uneicosane	2.849E-004
n-docosane	1.802E-004
n-tricosane	1.054E-004
n-Tetracosane	6.646E-005
n-pentacosane	3.962E-005
n-hexacosane	2.409E-005

EQUIPMENT SUMMARIES

N-Heptacosane	1.354E-005
n-Octacosane	9.098E-006
n-Nonacosane	5.580E-006
n-triacontane	3.445E-006
n-Dotriacontane	1.318E-006
n-Hexatriaconta	1.724E-007
2-Methyloctane	0.135
Cyclopentene	0.626
Methylcyclopent	0.419
Ethylcyclopenta	0.253
N-Propylcyclope	0.158
n-Butylcyclopen	0.098
N-Butylcyclohex	0.059
N-Hexylcyclo-C5	0.036
N-Octylcyclo-C5	0.013
N-Nonylcyclopen	7.797E-003
N-Decylcyclopen	4.723E-003
N-Decylcyclohex	2.823E-003
N-Dodecylcyclop	1.685E-003

N-Tridecylcyclo	9.904E-004
Ethylene	1024.371
Propylene	1.368
1-Butene	1.043
1-Pentene	0.795
1-Hexene	0.521
1-Heptene	0.330
1-Octene	0.206
1-Nonene	0.127
1-Decene	0.077
1-Undecene	0.047
1-Dodecene	0.029
1-Tridecene	0.017
1-Tetradecene	0.011
1-Pentadecene	6.399E-003
1-Hexadecene	3.868E-003
1-Heptadecene	2.409E-003
1-Octadecene	1.419E-003
1-Nonadecene	8.395E-004
1-Eicosene	5.082E-004
Toluene	0.269
Ethylbenzene	0.164
N-Propylbenzene	0.104
1-butylbenzene	0.062
N-Pentylbenzene	0.037
N-Hexylbenzene	0.023
N-Heptylbenzene	0.014
N-Octylbenzene	8.287E-003
N-Nonylbenzene	4.952E-003

EQUIPMENT SUMMARIES

N-Dodecylbenzen	1.107E-003
N-Decylbenzene	3.060E-003
N-Undecylbenzen	1.812E-003
Acetic Acid	0.401
Propionic Acid	0.274
N-Butyric Acid	0.157
Pentanoic Acid	0.092
N-Hexanoic Acid	0.053
Heptanoic Acid	0.035
N-Octanoic Acid	0.019
N-Nonanoic Acid	0.012
N-Decanoic Acid	6.559E-003
undecanoic acid	4.217E-003
Dodecanoic Acid	2.397E-003
N-Tridecanoic A	1.488E-003
N-Tetradecanoic	8.799E-004
Pentadecanoic A	5.445E-004
N-Hexadecanoic	2.728E-004
Heptadecanoic A	1.715E-004
n-Octadecanoic	1.210E-004
Carbon	1.000E-020
Nitrogen	7429.698

N-Heptylcyclope	0.021
Perylene	2.578E-005
pentacontane	6.216E-008
dopentacontane	4.315E-008
octatetracontan	8.875E-008
hexatetracontan	1.378E-007
tetratetraconta	2.211E-007
dotetracontane	3.215E-007
tetracontane	6.331E-007
octatriacontane	1.262E-006
tetratriacontan	4.875E-006
2-methyltetrade	7.417E-003
Linolenic Acid	2.257E-004
Linoleic Acid	2.494E-004
Oleic Acid	1.891E-004
Benzene	0.441
O-Xylene	0.141
M-Xylene	0.159
P-Xylene	0.161
Indan	0.075
1-Methylindene	0.044
Naphthalene	0.039
1-Methylnaphtha	0.020
1-propylnaphtha	8.965E-003
2,6-Dimethylnap	0.012
Sulfolane	3.364E-003

EQUIPMENT SUMMARIES

Varsol	0.038
Ethylene Glycol	9653.301
Air	6451.863
Oxygen	6335.405
Trimethylamine	0.920

D-607: Flash 5

Flash Summary

Equip. No.	102
Name	
Flash Mode	6
Param 1	15.0000
Heat duty MJ/min	-0.1380
Type	1
Diameter ft	2.5000
Length ft	9.3179
Vessel thickness ft	0.0208
Head thickness ft	0.0208
Straight flange ft	0.1667
Metal density lb/ft3	489.0240

K values:

triolein	3.013E-010
Water	580.441
Hydrogen	98620.414
Carbon Monoxide	1.045E+005
Carbon Dioxide	97546.836
Methane	53081.789
Ethane	25634.209
n-Propane	18.394
N-Butane	92967.492
N-Pentane	10.211
N-Hexane	6.484
N-Heptane	4.068
N-Octane	2.501
N-Nonane	1.508
N-Decane	0.889
N-Undecane	0.529
N-Dodecane	0.312
N-Tridecane	0.188
N-Tetradecane	0.110
N-Pentadecane	0.065
N-Hexadecane	0.038
N-Heptadecane	0.024
N-Octadecane	0.014
N-Nonadecane	8.634E-003
Eicosane	4.709E-003
uneicosane	2.779E-003
n-docosane	1.720E-003
n-tricosane	9.815E-004
n-Tetracosane	6.043E-004
n-pentacosane	3.526E-004
n-hexacosane	2.092E-004

EQUIPMENT SUMMARIES

N-Heptacosane	1.148E-004
n-Octacosane	7.562E-005
n-Nonacosane	4.547E-005
n-triacontane	2.746E-005
n-Dotriacontane	1.005E-005
n-Hexatriaconta	1.210E-006
2-Methyloctane	1.752
Cyclopentene	8.986
Methylcyclopent	5.918
Ethylcyclopenta	3.496
N-Propylcyclope	2.122
n-Butylcyclopen	1.283
N-Butylcyclohex	0.753
N-Hexylcyclo-C5	0.445
N-Octylcyclo-C5	0.153
N-Nonylcyclopen	0.090
N-Decylcyclopen	0.053
N-Decylcyclohex	0.031
N-Dodecylcyclop	0.018
N-Tridecylcyclo	0.010

Ethylene	16676.484
Propylene	20.161
1-Butene	14.531
1-Pentene	11.308
1-Hexene	7.294
1-Heptene	4.512
1-Octene	2.752
1-Nonene	1.652
1-Decene	0.986
1-Undecene	0.587
1-Dodecene	0.347
1-Tridecene	0.206
1-Tetradecene	0.122
1-Pentadecene	0.072
1-Hexadecene	0.042
1-Heptadecene	0.026
1-Octadecene	0.015
1-Nonadecene	8.632E-003
1-Eicosene	5.101E-003
Toluene	3.745
Ethylbenzene	2.233
N-Propylbenzene	1.388
1-butylbenzene	0.809
N-Pentylbenzene	0.475
N-Hexylbenzene	0.284
N-Heptylbenzene	0.166
N-Octylbenzene	0.097
N-Nonylbenzene	0.057

EQUIPMENT SUMMARIES

N-Dodecylbenzen	0.012
N-Decylbenzene	0.034
N-Undecylbenzen	0.020
Acetic Acid	5.721
Propionic Acid	3.868
N-Butyric Acid	2.156
Pentanoic Acid	1.230
N-Hexanoic Acid	0.696
Heptanoic Acid	0.440
N-Octanoic Acid	0.243
N-Nonanoic Acid	0.142
N-Decanoic Acid	0.078
undecanoic acid	0.049
Dodecanoic Acid	0.027
N-Tridecanoic A	0.016
N-Tetradecanoic	9.467E-003
Pentadecanoic A	5.723E-003
N-Hexadecanoic	2.813E-003
Heptadecanoic A	1.730E-003
n-Octadecanoic	1.195E-003
Carbon	1.000E-020
Nitrogen	1.250E+005
N-Heptylcyclope	0.261

Perylene	2.704E-004
pentacontane	3.668E-007
dopentacontane	2.476E-007
octatetracontan	5.389E-007
hexatetracontan	8.618E-007
tetratetraconta	1.427E-006
dotetracontane	2.137E-006
tetracontane	4.363E-006
octatriacontane	9.020E-006
tetratriacontan	3.741E-005
2-methyltetrade	0.084
Linolenic Acid	2.277E-003
Linoleic Acid	2.516E-003
Oleic Acid	1.891E-003
Benzene	6.309
O-Xylene	1.924
M-Xylene	2.163
P-Xylene	2.189
Indan	1.010
1-Methylindene	0.580
Naphthalene	0.506
1-Methylnaphtha	0.254
1-propylnaphtha	0.109
2,6-Dimethylnap	0.154
Sulfolane	0.044

Varsol	0.464
Ethylene Glycol	1.350E+005
Air	1.081E+005
Oxygen	1.059E+005
Trimethylamine	12.699

H.2.iii. Heat Exchangers

E-701 A/B: Post Cracking Cooler

Heat Exchanger Summary

Equip. No.	2
Name	
1st Stream dp psi	5.0000
2nd Stream dp psi	5.0000
1st Stream T Out F	439.0000
U Btu/hr-ft2-F	700.0000
Calc Ht Duty MJ/min	690.1989
LMTD (End points) F	287.9161
LMTD Corr Factor	1.0000
Calc U Btu/hr-ft2-F	700.0000
Calc Area ft2	194.7531
1st Stream Pout psia	255.0000
2nd Stream Pout psia	15.0000

```
P1 out specifed  psia      255.0000
P2 out specifed  psia       15.0000
```

E-702 A/B: Flash 2 Cooler

```
Heat Exchanger Summary

Equip. No.                      9
       Name
1st Stream dp  psi          5.0000
2nd Stream dp  psi          5.0000
1st Stream T Out  F       300.0000
2nd Stream T Out  F       113.0000
Calc Ht Duty  MJ/min      130.7126
LMTD (End points)  F      256.8069
LMTD Corr Factor            1.0000
Utility Option:                 1
1st Stream Pout  psia      95.0000
2nd Stream Pout  psia      50.0000
P1 out specifed  psia      95.0000
P2 out specifed  psia      50.0000
```

E-703 A/B: Pre Flash 3 Cooler

```
Heat Exchanger Summary

Equip. No.                     67
       Name
1st Stream dp  psi          5.0000
2nd Stream dp  psi          5.0000
1st Stream T Out  F       100.0000
2nd Stream T Out  F       113.0000
Calc Ht Duty  MJ/min       11.8956
LMTD (End points)  F       26.2956
LMTD Corr Factor            1.0000
Utility Option:                 1
1st Stream Pout  psia      25.0000
2nd Stream Pout  psia      50.0000
P1 out specifed  psia      25.0000
P2 out specifed  psia      50.0000
```

E-704 A/B: Syngas Cooler

```
Heat Exchanger Summary

Equip. No.                     37
       Name
1st Stream dp  psi          5.0000
2nd Stream dp  psi          5.0000
1st Stream T Out  F        90.0000
2nd Stream T Out  F       113.0000
Calc Ht Duty  MJ/min      115.4888
LMTD (End points)  F      106.6073
LMTD Corr Factor            1.0000
Utility Option:                 1
```

1st Stream Pout	psia	475.0000
2nd Stream Pout	psia	50.0000
P1 out specifed	psia	475.0000
P2 out specifed	psia	50.0000

E-705 A/B: Stage 1 Cooler

Heat Exchanger Summary

Equip. No.		82
Name		
1st Stream dp	psi	5.0000
2nd Stream dp	psi	5.0000
1st Stream T Out	F	125.0000
2nd Stream T Out	F	113.0000
Calc Ht Duty	MJ/min	25.2619
LMTD (End points)	F	91.4480
LMTD Corr Factor		1.0000
Utility Option:		1
1st Stream Pout	psia	55.0000
2nd Stream Pout	psia	50.0000
P1 out specifed	psia	55.0000
P2 out specifed	psia	50.0000

E-706 A/B: Stage 2 Cooler

Heat Exchanger Summary

Equip. No.		83
Name		
1st Stream dp	psi	5.0000
2nd Stream dp	psi	5.0000
1st Stream T Out	F	190.0000
2nd Stream T Out	F	113.0000
Calc Ht Duty	MJ/min	30.6045
LMTD (End points)	F	170.8476
LMTD Corr Factor		1.0000
Utility Option:		1
1st Stream Pout	psia	215.0000
2nd Stream Pout	psia	50.0000
P1 out specifed	psia	215.0000
P2 out specifed	psia	50.0000

E-707 A/B: Debutanizer Cooler

Heat Exchanger Summary

Equip. No.		71
Name		
1st Stream dp	psi	5.0000
1st Stream T Out	F	250.0000
Calc Ht Duty	MJ/min	-12.0926
LMTD Corr Factor		1.0000
1st Stream Pout	psia	465.0000
P1 out specifed	psia	465.0000

E-708 A/B: C6-C7 Cooler

Heat Exchanger Summary

Equip. No.	132
Name	
1st Stream dp psi	5.0000
1st Stream T Out F	325.0000
Calc Ht Duty MJ/min	-2.8332
LMTD Corr Factor	1.0000
1st Stream Pout psia	15.0000
P1 out specifed psia	15.0000

E-709 A/B: C4-C5 Cooler

Heat Exchanger Summary

Equip. No.	133
Name	
1st Stream dp psi	5.0000
1st Stream T Out F	200.0000
Calc Ht Duty MJ/min	-2.3825
LMTD Corr Factor	1.0000
1st Stream Pout psia	15.0000
P1 out specifed psia	15.0000

E-710 A/B: C8-C9 Cooler

Heat Exchanger Summary

Equip. No.	43
Name	
1st Stream dp psi	5.0000
1st Stream T Out F	400.0000
Calc Ht Duty MJ/min	-18.8425
LMTD Corr Factor	1.0000
1st Stream Pout psia	20.0000
P1 out specifed psia	20.0000

E-711 A/B: C10-C11 Cooler

Heat Exchanger Summary

Equip. No.	124
Name	
1st Stream dp psi	5.0000
1st Stream T Out F	475.0000
Calc Ht Duty MJ/min	-3.1658
LMTD Corr Factor	1.0000
1st Stream Pout psia	20.0000
P1 out specifed psia	20.0000

E-712 A/B: C11 Cooler

```
Heat Exchanger Summary

Equip. No.                    125
       Name
1st Stream dp  psi          5.0000
1st Stream T Out  F       440.0000
Calc Ht Duty  MJ/min       -9.7865
LMTD Corr Factor            1.0000
1st Stream Pout  psia      20.0000
P1 out specifed  psia      20.0000
```

E-713 A/B: Flash 4 Cooler

```
Heat Exchanger Summary

Equip. No.                     99
       Name
1st Stream dp  psi          5.0000
2nd Stream dp  psi          5.0000
1st Stream T Out  F       350.0000
2nd Stream T Out  F       113.0000
Calc Ht Duty  MJ/min       26.8885
LMTD (End points)  F      367.4783
LMTD Corr Factor            1.0000
Utility Option:                1
1st Stream Pout  psia     315.0000
2nd Stream Pout  psia      50.0000
P1 out specifed  psia     315.0000
P2 out specifed  psia      50.0000
```

E-714 A/B: Pre Jet Diesel Cut Cooler

```
Heat Exchanger Summary

Equip. No.                     68
       Name
1st Stream dp  psi          5.0000
2nd Stream dp  psi          5.0000
1st Stream T Out  F       400.0000
2nd Stream VF Out      1.0000e-005
Calc Ht Duty  MJ/min        6.4320
LMTD (End points)  F      210.7112
LMTD Corr Factor            1.0000
Utility Option:                1
1st Stream Pout  psia      25.0000
2nd Stream Pout  psia      50.0000
P1 out specifed  psia      25.0000
P2 out specifed  psia      50.0000
```

E-801 A/B: TTCR Preheat

```
Heat Exchanger Summary
```

```
Equip. No.                      74
       Name
1st Stream dp  psi          5.0000
2nd Stream dp  psi          5.0000
1st Stream T Out  F       770.0001
2nd Stream T Out  F       700.0001
Calc Ht Duty  MJ/min      303.2726
LMTD (End points)  F       72.7795
LMTD Corr Factor            1.0000
Utility Option:                  1
1st Stream Pout  psia     275.0000
2nd Stream Pout  psia     870.0000
P1 out specifed  psia     275.0000
P2 out specifed  psia     870.0000
```

E-802 A/B: Atmospheric Column Preheat

```
Heat Exchanger Summary

Equip. No.                     130
       Name
1st Stream dp  psi          5.0000
1st Stream T Out  F       275.0000
Calc Ht Duty  MJ/min      135.5245
LMTD Corr Factor            1.0000
1st Stream Pout  psia      20.0000
P1 out specifed  psia      20.0000
```

E-803 A/B: C3-C4 Heater

```
Heat Exchanger Summary

Equip. No.                      54
       Name
1st Stream dp  psi          5.0000
1st Stream T Out  F       275.0000
Calc Ht Duty  MJ/min        0.0385
LMTD Corr Factor            1.0000
1st Stream Pout  psia      10.0000
P1 out specifed  psia      10.0000
```

E-804 A/B: Fatty Acid Decarbox Heater

```
Heat Exchanger Summary

Equip. No.                      98
       Name
1st Stream dp  psi          5.0000
1st Stream T Out  F       608.0001
Calc Ht Duty  MJ/min        9.7806
LMTD Corr Factor            1.0000
1st Stream Pout  psia     445.0000
P1 out specifed  psia     445.0000
```

E-1001 A/B: Naphtha Cooler

```
Heat Exchanger Summary

Equip. No.                     62
       Name
1st Stream T Out  F         90.0000
Calc Ht Duty  MJ/min       -15.1794
LMTD Corr Factor             1.0000
1st Stream Pout  psia       18.0000
P1 out specifed  psia       18.0000
```

E-1002 A/B: Jet Cooler

```
Heat Exchanger Summary

Equip. No.                     31
       Name
1st Stream dp  psi           1.0000
1st Stream T Out  F         90.0000
Calc Ht Duty  MJ/min       -86.4607
LMTD Corr Factor             1.0000
1st Stream Pout  psia       14.0000
P1 out specifed  psia       14.0000
```

E-1003 A/B: Diesel Cooler 1

```
Heat Exchanger Summary

Equip. No.                     32
       Name
1st Stream dp  psi           1.0000
1st Stream T Out  F        140.0000
Calc Ht Duty  MJ/min      -171.8006
LMTD Corr Factor             1.0000
1st Stream Pout  psia       24.0000
P1 out specifed  psia       24.0000
```

E-1004 A/B: Diesel Cooler 2

```
Heat Exchanger Summary

Equip. No.                     33
       Name
1st Stream dp  psi           1.0000
1st Stream T Out  F         90.0000
Calc Ht Duty  MJ/min       -13.5787
LMTD Corr Factor             1.0000
1st Stream Pout  psia       23.0000
P1 out specifed  psia       23.0000
```

E-1005 A/B: Fuel Oil Cooler

```
Heat Exchanger Summary
```

```
Equip. No.                       15
       Name
1st Stream dp  psi           5.0000
2nd Stream dp  psi           1.0000
1st Stream T Out  F        140.0000
Calc Ht Duty  MJ/min        -2.0372
LMTD (End points)  F        33.0084
LMTD Corr Factor             1.0000
1st Stream Pout  psia       20.0000
2nd Stream Pout  psia      127.4385
P1 out specifed  psia       20.0000
```

H.2.iv. Compressors

G-201 A/B: Flash 2 Compressor

```
Compressor Summary

Equip. No.                       12
       Name
Pressure out  psia          60.0000
Type of Compressor                1
Efficiency                   0.5500
Actual power  MJ/min         1.0062
Cp/Cv                        1.0739
Theoretical power            0.5534
 (MJ/min)
Ideal Cp/Cv                  1.0686
Calc Pout  psia             60.0000
Calc. mass flowrate              20
 (lb/min)
```

G-202 A/B: Flash 2 Compressor

```
Compressor Summary

Equip. No.                       21
       Name
Pressure out  psia          35.0000
Type of Compressor                1
Efficiency                   0.5500
Actual power  MJ/min         0.0003
Cp/Cv                        1.1120
Theoretical power            0.0001
 (MJ/min)
Ideal Cp/Cv                  1.1100
Calc Pout  psia             35.0000
Calc. mass flowrate               0
 (lb/min)
```

G-203 A/B Stage 1: Light End Compressor

```
Compressor Summary
```

Equip. No.	79
Name	
Pressure out psia	60.0000
Type of Compressor	1
Efficiency	0.5500
Actual power MJ/min	32.1063
Cp/Cv	1.2018
Theoretical power (MJ/min)	17.6585
Ideal Cp/Cv	1.1957
Calc Pout psia	60.0000
Calc. mass flowrate (lb/min)	396

G-203 A/B Stage 2: Light End Compressor

Compressor Summary

Equip. No.	80
Name	
Pressure out psia	220.0000
Type of Compressor	1
Efficiency	0.5000
Actual power MJ/min	38.1991
Cp/Cv	1.1976
Theoretical power (MJ/min)	19.0995
Ideal Cp/Cv	1.1810
Calc Pout psia	220.0000
Calc. mass flowrate (lb/min)	396

G-203 A/B Stage 3: Light End Compressor

Compressor Summary

Equip. No.	81
Name	
Pressure out psia	480.0000
Type of Compressor	1
Efficiency	0.5500
Actual power MJ/min	20.6110
Cp/Cv	1.2108
Theoretical power (MJ/min)	11.3361
Ideal Cp/Cv	1.1622
Calc Pout psia	480.0000
Calc. mass flowrate (lb/min)	396

H.2.v. Pumps

L-201 A/B: Pre Cracking Pump

```
Pump Summary

Equip. No.                        3
       Name
Output pressure  psia       40.0000
Efficiency                   0.6500
Calculated power             0.3893
 (MJ/min)
Calculated Pout  psia       40.0000
Head  ft                    84.7726
Vol. flow rate              51.8054
 (ft3/min)
Mass flow rate  lb/min    2200.0000
```

L-203 A/B: Post Extractor Pump

```
Pump Summary

Equip. No.                       17
       Name
Output pressure  psia       25.0000
Efficiency                   0.6500
Calculated power             0.0421
 (MJ/min)
Calculated Pout  psia       25.0000
Head  ft                    14.3202
Vol. flow rate              28.0245
 (ft3/min)
Mass flow rate  lb/min    1409.0350
```

L-204 A/B: Atmosheric Reflux

```
Pump Summary

Equip. No.                       64
       Name
Output pressure  psia       19.0000
Efficiency                   0.6500
Calculated power             0.0091
 (MJ/min)
Calculated Pout  psia       19.0000
Head  ft                    14.7279
Vol. flow rate               6.3758
 (ft3/min)
Mass flow rate  lb/min     296.1079
```

L-205 A/B: Vacuum Reflux

```
Pump Summary
```

```
Equip. No.                    66
       Name
Output pressure  psia       20.0000
Efficiency                   0.6500
Calculated power             0.0729
 (MJ/min)
Calculated Pout  psia       20.0000
Head  ft                    63.0675
Vol. flow rate              12.7701
 (ft3/min)
Mass flow rate  lb/min     553.9932
```

L-206 A/B: Vacuum Bottoms

```
Pump Summary

Equip. No.                    70
       Name
Output pressure  psia       20.0000
Efficiency                   0.6500
Calculated power             0.0578
 (MJ/min)
Calculated Pout  psia       20.0000
Head  ft                    49.5386
Vol. flow rate              13.7345
 (ft3/min)
Mass flow rate  lb/min     558.9340
```

L-209 A/B: Syngas Column Reflux

```
Pump Summary

Equip. No.                    72
       Name
Output pressure  psia      470.0000
Efficiency                   0.6500
Calculated power             0.0152
 (MJ/min)
Calculated Pout  psia      470.0000
Head  ft                    27.1590
Vol. flow rate              10.1120
 (ft3/min)
Mass flow rate  lb/min     268.0757
```

L-210 A/B: Debutanizer Reflux

```
Pump Summary

Equip. No.                    73
       Name
Output pressure  psia      120.0000
Efficiency                   0.6500
Calculated power             0.0019
 (MJ/min)
Calculated Pout  psia      120.0000
```

```
Head  ft                      22.0181
Vol. flow rate                 1.2973
 (ft3/min)
Mass flow rate  lb/min        42.4224
```

L-211 A/B: Hexane Splitter Bottoms

```
Pump Summary

Equip. No.                        76
       Name
Output pressure  psia         25.0000
Efficiency                     0.6500
Calculated power               0.0335
 (MJ/min)
Calculated Pout  psia         25.0000
Head  ft                      37.3557
Vol. flow rate                10.1459
 (ft3/min)
Mass flow rate  lb/min       430.2186
```

L-212 A/B: Hexane Splitter Reflux

```
Pump Summary

Equip. No.                        75
       Name
Output pressure  psia         25.0000
Efficiency                     0.6500
Calculated power               0.0016
 (MJ/min)
Calculated Pout  psia         25.0000
Head  ft                      51.8551
Vol. flow rate                 0.3511
 (ft3/min)
Mass flow rate  lb/min        14.6234
```

L-213 A/B: Naphtha Reflux

```
Pump Summary

Equip. No.                        77
       Name
Output pressure  psia         18.0000
Efficiency                     0.6500
Calculated power               0.0038
 (MJ/min)
Calculated Pout  psia         18.0000
Head  ft                      17.4987
Vol. flow rate                 2.5153
 (ft3/min)
Mass flow rate  lb/min       103.4960
```

L-214 A/B: Pre Jet Pump

```
Pump Summary

Equip. No.                      20
       Name
Output pressure  psia       30.0000
Efficiency                   0.6500
Calculated power             0.1270
 (MJ/min)
Calculated Pout  psia       30.0000
Head  ft                    91.3916
Vol. flow rate              16.2488
 (ft3/min)
Mass flow rate  lb/min     665.6561
```

L-215 A/B: Jet Reflux

```
Pump Summary

Equip. No.                      84
       Name
Output pressure  psia       15.0000
Efficiency                   0.6500
Calculated power             0.0052
 (MJ/min)
Calculated Pout  psia       15.0000
Head  ft                    18.1731
Vol. flow rate               3.4387
 (ft3/min)
Mass flow rate  lb/min     136.2380
```

L-216 A/B: Jet Bottoms

```
Pump Summary

Equip. No.                      85
       Name
Output pressure  psia       25.0000
Efficiency                   0.6500
Calculated power             0.0393
 (MJ/min)
Calculated Pout  psia       25.0000
Head  ft                    35.5656
Vol. flow rate              14.5286
 (ft3/min)
Mass flow rate  lb/min     529.4181
```

L-217 A/B: Diesel Reflux

```
Pump Summary

Equip. No.                      86
       Name
```

```
Output pressure  psia       20.0000
Efficiency                   0.6500
Calculated power             0.0216
 (MJ/min)
Calculated Pout  psia       20.0000
Head  ft                    19.7548
Vol. flow rate              14.3975
 (ft3/min)
Mass flow rate  lb/min     524.7431
```

L-218 A/B: Water Removal Reflux

```
Pump Summary

Equip. No.                    64
       Name
Output pressure  psia        7.0000
Efficiency                   0.6500
Calculated power             0.0434
 (MJ/min)
Calculated Pout  psia        7.0000
Head  ft                    12.7453
Vol. flow rate              28.8682
 (ft3/min)
Mass flow rate  lb/min    1630.8086
```

L-219 A/B: Water Removal Bottoms

```
Pump Summary

Equip. No.                    55
       Name
Output pressure  psia       25.0000
Efficiency                   0.6500
Calculated power             0.0300
 (MJ/min)
Calculated Pout  psia       25.0000
Head  ft                    40.0796
Vol. flow rate               6.6542
 (ft3/min)
Mass flow rate  lb/min     358.6144
```

L-220 A/B: Solvent Recycle Pump

```
Pump Summary

Equip. No.                    84
       Name
Output pressure  psia       20.0000
Efficiency                   0.6500
Calculated power             0.0956
 (MJ/min)
Calculated Pout  psia       20.0000
Head  ft                    26.9505
Vol. flow rate              31.8048
```

```
 (ft3/min)
Mass flow rate  lb/min    1699.3712
```

L-221 A/B: Acetic Acid Reflux

```
Pump Summary

Equip. No.                    70
       Name
Output pressure  psia      15.0000
Efficiency                  0.6500
Calculated power            0.0017
 (MJ/min)
Calculated Pout  psia      15.0000
Head  ft                   11.9572
Vol. flow rate              1.1386
 (ft3/min)
Mass flow rate  lb/min     68.5626
```

L-222 A/B: C3 Bottoms

```
Pump Summary

Equip. No.                    63
       Name
Output pressure  psia      20.0000
Efficiency                  0.6500
Calculated power            0.0310
 (MJ/min)
Calculated Pout  psia      20.0000
Head  ft                   53.1194
Vol. flow rate              5.7216
 (ft3/min)
Mass flow rate  lb/min    279.1892
```

L-223 A/B: C3 Reflux

```
Pump Summary

Equip. No.                   131
       Name
Output pressure  psia      25.0000
Efficiency                  0.6500
Calculated power            0.0089
 (MJ/min)
Calculated Pout  psia      25.0000
Head  ft                   53.6010
Vol. flow rate              1.2854
 (ft3/min)
Mass flow rate  lb/min     79.4254
```

L-224 A/B: C6-C7 Reflux

```
Pump Summary
```

Equip. No.		134
Name		
Output pressure	psia	20.0000
Efficiency		0.6500
Calculated power (MJ/min)		0.0007
Calculated Pout	psia	20.0000
Head	ft	14.6918
Vol. flow rate (ft3/min)		0.4610
Mass flow rate	lb/min	22.5920

L-225 A/B: C6-C7 Bottoms

Pump Summary

Equip. No.		62
Name		
Output pressure	psia	25.0000
Efficiency		0.6500
Calculated power (MJ/min)		0.0176
Calculated Pout	psia	25.0000
Head	ft	32.9454
Vol. flow rate (ft3/min)		5.8706
Mass flow rate	lb/min	256.5971

L-226 A/B: C4-C5 Reflux

Pump Summary

Equip. No.		135
Name		
Output pressure	psia	15.0000
Efficiency		0.6500
Calculated power (MJ/min)		0.0002
Calculated Pout	psia	15.0000
Head	ft	23.9441
Vol. flow rate (ft3/min)		0.0657
Mass flow rate	lb/min	3.5584

L-227 A/B: C4-C5 Bottoms

Pump Summary

Equip. No.		61
Name		
Output pressure	psia	25.0000
Efficiency		0.6500
Calculated power (MJ/min)		0.0022

Calculated Pout	psia	25.0000
Head	ft	54.8009
Vol. flow rate (ft3/min)		0.3812
Mass flow rate	lb/min	19.0336

L-228 A/B: C3-C4 Reflux

Pump Summary

Equip. No.		78
Name		
Output pressure	psia	15.0000
Efficiency		0.6500
Calculated power (MJ/min)		3.3118e-005
Calculated Pout	psia	15.0000
Head	ft	13.1308
Vol. flow rate (ft3/min)		0.0220
Mass flow rate	lb/min	1.2083

L-229 A/B: C3-C4 Bottoms

Pump Summary

Equip. No.		85
Name		
Output pressure	psia	20.0000
Efficiency		0.6500
Calculated power (MJ/min)		0.0001
Calculated Pout	psia	20.0000
Head	ft	27.7741
Vol. flow rate (ft3/min)		0.0442
Mass flow rate	lb/min	2.2935

L-230 A/B: C5-C6 Bottoms

Pump Summary

Equip. No.		94
Name		
Output pressure	psia	20.0000
Efficiency		0.6500
Calculated power (MJ/min)		0.0005
Calculated Pout	psia	20.0000
Head	ft	18.1320
Vol. flow rate (ft3/min)		0.2619
Mass flow rate	lb/min	12.4796

L-231 A/B: C5-C6 Reflux

```
Pump Summary

Equip. No.                      89
       Name
Output pressure  psia       15.0000
Efficiency                   0.6500
Calculated power        4.0173e-005
 (MJ/min)
Calculated Pout  psia       15.0000
Head  ft                     2.9365
Vol. flow rate               0.1337
 (ft3/min)
Mass flow rate  lb/min       6.5540
```

L-232 A/B: C8-C9 Bottoms

```
Pump Summary

Equip. No.                      45
       Name
Output pressure  psia       25.0000
Efficiency                   0.6500
Calculated power             0.0258
 (MJ/min)
Calculated Pout  psia       25.0000
Head  ft                    61.8866
Vol. flow rate               4.5211
 (ft3/min)
Mass flow rate  lb/min     199.8759
```

L-233 A/B: C8-C9 Reflux

```
Pump Summary

Equip. No.                      52
       Name
Output pressure  psia       25.0000
Efficiency                   0.6500
Calculated power             0.0068
 (MJ/min)
Calculated Pout  psia       25.0000
Head  ft                    57.8129
Vol. flow rate               1.1985
 (ft3/min)
Mass flow rate  lb/min      56.7212
```

L-234 A/B: C7-C8 Bottoms

```
Pump Summary

Equip. No.                      96
       Name
Output pressure  psia       20.0000
Efficiency                   0.6500
```

Calculated power (MJ/min)	0.0022
Calculated Pout psia	20.0000
Head ft	42.8958
Vol. flow rate (ft3/min)	0.5138
Mass flow rate lb/min	24.1477

L-235 A/B: C7-C8 Relfux

Pump Summary

Equip. No.	95
Name	
Output pressure psia	15.0000
Efficiency	0.6500
Calculated power (MJ/min)	0.0019
Calculated Pout psia	15.0000
Head ft	27.2969
Vol. flow rate (ft3/min)	0.6861
Mass flow rate lb/min	32.5734

L-236 A/B: C10-C11 Bottoms

Pump Summary

Equip. No.	126
Name	
Output pressure psia	25.0000
Efficiency	0.6500
Calculated power (MJ/min)	0.0216
Calculated Pout psia	25.0000
Head ft	69.8128
Vol. flow rate (ft3/min)	3.4152
Mass flow rate lb/min	147.9311

L-237 A/B: C10-C11 Reflux

Pump Summary

Equip. No.	128
Name	
Output pressure psia	25.0000
Efficiency	0.6500
Calculated power (MJ/min)	0.0071
Calculated Pout psia	25.0000
Head ft	65.3793
Vol. flow rate (ft3/min)	1.1231
Mass flow rate lb/min	51.9450

L-239 A/B: C9-C10 Bottoms

```
Pump Summary

Equip. No.                      105
       Name
Output pressure  psia       20.0000
Efficiency                   0.6500
Calculated power             0.0026
 (MJ/min)
Calculated Pout  psia       20.0000
Head  ft                    49.8512
Vol. flow rate               0.5458
 (ft3/min)
Mass flow rate  lb/min      25.2249
```

L-240 A/B: C11 Reflux

```
Pump Summary

Equip. No.                      108
       Name
Output pressure  psia       15.0000
Efficiency                   0.6500
Calculated power             0.0009
 (MJ/min)
Calculated Pout  psia       15.0000
Head  ft                    40.7074
Vol. flow rate               0.2283
 (ft3/min)
Mass flow rate  lb/min      10.4976
```

L-241 A/B: C11 Bottoms

```
Pump Summary

Equip. No.                       97
       Name
Output pressure  psia      450.0000
Efficiency                   0.6500
Calculated power             0.4189
 (MJ/min)
Calculated Pout  psia      450.0000
Head  ft                  1460.1587
Vol. flow rate               3.1107
 (ft3/min)
Mass flow rate  lb/min     137.4335
```

L-244 A/B: C9-C10 Reflux

```
Pump Summary

Equip. No.                      104
```

Name	
Output pressure psia	15.0000
Efficiency	0.6500
Calculated power (MJ/min)	0.0019
Calculated Pout psia	15.0000
Head ft	34.2594
Vol. flow rate (ft3/min)	0.5779
Mass flow rate lb/min	26.7200

L-258 A/B: Flash 3 Pump

Pump Summary

Equip. No.	69
Name	
Output pressure psia	25.0000
Efficiency	0.6500
Calculated power (MJ/min)	0.0021
Calculated Pout psia	25.0000
Head ft	31.5963
Vol. flow rate (ft3/min)	0.6894
Mass flow rate lb/min	31.4188

H.3. Alternative Base Design

H.3.i. Distillation Columns

D-201: Atmospheric Column

TOWR Rigorous Distillation Summary

Equip. No.	14
Name	
No. of stages	7
1st feed stage	3
Top pressure psia	18.0000
Condenser mode	7
Condenser spec.	0.5000
Cond comp i	18
Reboiler mode	7
Reboiler spec.	0.9900
Reboiler comp i	94
Initial flag	1
Calc cond duty MJ/min	-119.5751
Calc rebr duty MJ/min	354.0187
Est. Dist. rate (lbmol/min)	5.5732
Est. Reflux rate (lbmol/min)	5.2486
Est. T top F	211.6549
Est. T bottom F	711.7022

Est. T 2 F	493.2700
Tray type	3
Column diameter ft	8.0000
Tray space ft	2.0000
Thickness (top) ft	0.0052
Thickness (bot) ft	0.0052
No of sections	1
Bottom Pout psia	25.0000
Calc Reflux ratio	0.0745
Calc Reflux mole (lbmol/min)	0.2193
Calc Reflux mass (lb/min)	27.9062
No of passes (S1)	1
Weir side width ft	1.4583
Weir height ft	0.1667
System factor	1.0000
Optimization flag	1

D-202: Vacuum Column

TOWR Rigorous Distillation Summary

Equip. No.	51
Name	
No. of stages	20
1st feed stage	5
Top pressure psia	4.0000
Condenser mode	7
Condenser spec.	0.9000
Cond comp i	26
Reboiler mode	7
Reboiler spec.	0.9900
Reboiler comp i	29
Initial flag	6
Calc cond duty MJ/min	-263.1205
Calc rebr duty MJ/min	207.6720
Est. Dist. rate (lbmol/min)	3.3561
Est. Reflux rate (lbmol/min)	3.5093
Est. T top F	444.0000
Est. T bottom F	669.0714
Est. T 2 F	512.9335
Tray type	3
Column diameter ft	9.5000
Tray space ft	2.0000
No of sections	1
Bottom Pout psia	6.0000
Calc Reflux ratio	1.3479
Calc Reflux mole (lbmol/min)	4.1485
Calc Reflux mass (lb/min)	940.3527
No of passes (S1)	1
Weir side width ft	1.7083

```
Weir height  ft              0.1667
System factor                1.0000
Optimization flag               1
```

D-203: Hexane Splitter

```
TOWR Rigorous Distillation Summary

Equip. No.                     29
       Name
No. of stages                  12
1st feed stage                  4
Top pressure  psia          15.0000
Cond pressure drop           5.0000
 (psi)
Colm pressure drop           5.0000
 (psi)
Condenser type                  1
Condenser mode                  7
Condenser spec.              0.9500
Cond comp i                    11
Reboiler mode                   7
Reboiler spec.               0.9900
Reboiler comp i                12
Initial flag                    1
Calc cond duty  MJ/min     -67.8690
Calc rebr duty  MJ/min     110.1022
Est. Dist. rate              2.7120
 (lbmol/min)
Est. Reflux rate             2.3699
 (lbmol/min)
Est. T top  F              123.8975
Est. T bottom  F           352.3092
Est. T 2  F                 48.4705
Tray type                       3
Column diameter  ft          5.0000
Tray space  ft               2.0000
Thickness (top)  ft          0.0052
Thickness (bot)  ft          0.0078
No of sections                  1
Calc Reflux ratio            1.8539
Calc Reflux mole             4.2113
 (lbmol/min)
Calc Reflux mass           348.9127
 (lb/min)
No of passes (S1)               1
Weir side width  ft          0.8958
Weir height  ft              0.1667
System factor                1.0000
Optimization flag               1
```

D-204: Jet Diesel Cut Column

```
                      TOWR Rigorous Distillation Summary

Equip. No.                     26
```

Name	
No. of stages	25
1st feed stage	13
Top pressure psia	15.0000
Condenser mode	7
Condenser spec.	0.2500
Cond comp i	20
Reboiler mode	7
Reboiler spec.	0.9990
Reboiler comp i	21
Initial flag	1
Calc cond duty MJ/min	-136.8654
Calc rebr duty MJ/min	170.2632
Est. Dist. rate (lbmol/min)	2.6149
Est. Reflux rate (lbmol/min)	5.0238
Est. T top F	100.0000
Est. T bottom F	654.9268
Est. T 2 F	517.7233
Tray type	3
Column diameter ft	8.5000
Tray space ft	2.0000
Thickness (top) ft	0.0052
Thickness (bot) ft	0.0130
No of sections	1
Bottom Pout psia	25.0000
Calc Reflux ratio	1.5190
Calc Reflux mole (lbmol/min)	1.4942
Calc Reflux mass (lb/min)	247.6491
No of passes (S1)	1
Weir side width ft	1.5208
Weir height ft	0.1667
System factor	1.0000
Optimization flag	1

D-205: Naphtha-Jet Cut Column

TOWR Rigorous Distillation Summary

Equip. No.	28
Name	
No. of stages	30
1st feed stage	7
Top pressure psia	18.0000
Cond pressure drop (psi)	5.0000
Colm pressure drop (psi)	5.0000
Condenser mode	1
Condenser spec.	1.2500
Cond comp i	14
Reboiler mode	7
Reboiler spec.	0.9965

```
Reboiler comp i                 74
Initial flag                     6
Calc cond duty  MJ/min    -52.7125
Calc rebr duty  MJ/min     63.9680
Est. Dist. rate             1.7783
 (lbmol/min)
Est. Reflux rate            2.2229
 (lbmol/min)
Est. T top  F             255.0963
Est. T bottom  F          447.7938
Est. T 2  F               279.1875
Tray type                        3
Column diameter  ft         4.5000
Tray space  ft              2.0000
Thickness (top)  ft         0.0052
Thickness (bot)  ft         0.0286
No of sections                   1
Calc Reflux ratio           1.2500
Calc Reflux mole            1.7463
 (lbmol/min)
Calc Reflux mass          185.2892
 (lb/min)
No of passes (S1)                1
Weir side width  ft         0.8333
Weir height  ft             0.1667
System factor               1.0000
Optimization flag                1
```

D-206: Diesel-Fuel Oil Cut Column

```
TOWR Rigorous Distillation Summary

Equip. No.                      34
       Name
No. of stages                   40
1st feed stage                  28
Top pressure  psia         20.0000
Cond pressure drop          5.0000
 (psi)
Colm pressure drop          5.0000
 (psi)
Condenser mode                   7
Condenser spec.             0.9500
Cond comp i                     26
Reboiler mode                    7
Reboiler spec.              0.9900
Reboiler comp i                 28
Initial flag                     1
Calc cond duty  MJ/min   -106.7084
Calc rebr duty  MJ/min    117.2880
Est. Dist. rate             3.0575
 (lbmol/min)
Est. Reflux rate            7.6994
 (lbmol/min)
Est. T top  F             603.0223
Est. T bottom  F          883.3350
```

```
Est. T 2  F              625.3803
Tray type                    3
Column diameter  ft        8.0000
Tray space  ft             2.0000
Thickness (top)  ft        0.0078
Thickness (bot)  ft        0.0286
No of sections               1
Calc Reflux ratio          0.7699
Calc Reflux mole           1.4790
 (lbmol/min)
Calc Reflux mass         363.1806
 (lb/min)
No of passes (S1)            1
Weir side width  ft        1.4583
Weir height  ft            0.1667
System factor              1.0000
Optimization flag            1
```

D-207: Syngas Column

```
TOWR Rigorous Distillation Summary

Equip. No.                  115
       Name
No. of stages                40
1st feed stage                5
Top pressure  psia       400.0000
Condenser type               1
Condenser mode               7
Condenser spec.            0.9700
Cond comp i                  8
Reboiler mode                7
Reboiler spec.             0.9900
Reboiler comp i              9
Initial flag                 1
Calc cond duty  MJ/min   -27.9471
Calc rebr duty  MJ/min    54.7974
Est. Dist. rate           13.0636
 (lbmol/min)
Est. Reflux rate           0.2556
 (lbmol/min)
Est. T top  F             -6.8919
Est. T bottom  F         344.0276
Tray type                    3
Column diameter  ft        7.0000
Tray space  ft             2.0000
Thickness (top)  ft        0.1250
Thickness (bot)  ft        0.1250
No of sections               1
Calc Reflux ratio          0.3942
Calc Reflux mole           4.1170
 (lbmol/min)
Calc Reflux mass         170.0984
 (lb/min)
No of passes (S1)            1
Weir side width  ft        1.2708
```

```
Weir height  ft              0.1667
System factor                1.0000
Optimization flag              1
```

D-208: Debutanizer

```
TOWR Rigorous Distillation Summary

Equip. No.                     66
       Name
No. of stages                  12
1st feed stage                  8
Top pressure  psia         120.0000
Cond pressure drop           5.0000
 (psi)
Colm pressure drop           5.0000
 (psi)
Condenser type                 1
Condenser mode                 7
Condenser spec.              0.9500
Cond comp i                    9
Reboiler mode                  7
Reboiler spec.               0.9700
Reboiler comp i               10
Initial flag                   1
Calc cond duty  MJ/min     -41.9807
Calc rebr duty  MJ/min      49.3136
Est. Dist. rate              1.7103
 (lbmol/min)
Est. Reflux rate             3.6289
 (lbmol/min)
Est. T top  F              149.9970
Est. T bottom  F           795.5644
Tray type                      3
Column diameter  ft         11.5000
Tray space  ft               2.0000
Thickness (top)  ft          0.0599
Thickness (bot)  ft          0.0599
No of sections                 1
Calc Reflux ratio            5.9823
Calc Reflux mole             4.9804
 (lbmol/min)
Calc Reflux mass           289.8417
 (lb/min)
No of passes (S1)              1
Weir side width  ft          2.0833
Weir height  ft              0.1667
System factor                1.0000
Optimization flag              1
```

D-209: C5 Product Column

```
TOWR Rigorous Distillation Summary

Equip. No.                     33
       Name
```

No. of stages	17
1st feed stage	10
Condenser mode	7
Condenser spec.	0.9900
Cond comp i	10
Reboiler mode	7
Reboiler spec.	0.9900
Reboiler comp i	11
Initial flag	6
Calc cond duty MJ/min	-38.5057
Calc rebr duty MJ/min	26.8638
Est. Dist. rate (lbmol/min)	0.7702
Est. Reflux rate (lbmol/min)	0.7734
Est. T top F	109.0722
Est. T bottom F	183.1717
Est. T 2 F	114.7068
Tray type	3
Column diameter ft	3.5000
Tray space ft	2.0000
Thickness (top) ft	0.0052
Thickness (bot) ft	0.0130
No of sections	1
Calc Reflux ratio	3.2927
Calc Reflux mole (lbmol/min)	2.5065
Calc Reflux mass (lb/min)	176.3069
No of passes (S1)	1
Weir side width ft	0.6458
Weir height ft	0.1667
System factor	1.0000
Optimization flag	1

H.3.ii. Flash Drums

D-101: Flash 1

Flash Summary

Equip. No.	7
Name	
Flash Mode	6
Param 1	100.0000
Heat duty MJ/min	-1.1231
Diameter ft	4.0000
Length ft	16.0000
Vessel thickness ft	0.0313
Head thickness ft	0.0313
Straight flange ft	0.1667
Metal density lb/ft3	489.0240

K values:	
triolein	0.024
Water	23.084

Hydrogen	85.813
Carbon Monoxide	71.026
Carbon Dioxide	31.460
Methane	47.577
Ethane	19.666
n-Propane	11.531
N-Butane	6.781
N-Pentane	4.112
N-Hexane	2.515
N-Heptane	1.590
N-Octane	1.005
N-Nonane	0.637
N-Decane	0.410
N-Undecane	0.266
N-Dodecane	0.172
N-Tridecane	0.113
N-Tetradecane	0.074
N-Pentadecane	0.049
N-Hexadecane	0.031
N-Heptadecane	0.022
N-Octadecane	0.016
N-Nonadecane	0.011
Eicosane	7.602E-003
uneicosane	4.857E-003
n-docosane	3.508E-003
n-tricosane	2.333E-003
n-Tetracosane	1.626E-003
n-pentacosane	1.166E-003
n-hexacosane	8.134E-004
N-Heptacosane	5.439E-004

EQUIPMENT SUMMARIES

n-Octacosane	4.229E-004
n-Nonacosane	3.231E-004
n-triacontane	2.343E-004
n-Dotriacontane	1.336E-004
n-Hexatriaconta	4.449E-005
2-Methyloctane	0.728
Cyclopentene	3.718
Methylcyclopent	2.336
Ethylcyclopenta	1.409
N-Propylcyclope	0.855
n-Butylcyclopen	0.562
N-Butylcyclohex	0.339
N-Hexylcyclo-C5	0.224
N-Octylcyclo-C5	0.095
N-Nonylcyclopen	0.061
N-Decylcyclopen	0.040
N-Decylcyclohex	0.025
N-Dodecylcyclop	0.019
N-Tridecylcyclo	0.013

Ethylene	23.352
Propylene	12.391
1-Butene	7.338
1-Pentene	4.476
1-Hexene	2.690
1-Heptene	1.696
1-Octene	1.067
1-Nonene	0.676
1-Decene	0.435
1-Undecene	0.282
1-Dodecene	0.183
1-Tridecene	0.120
1-Tetradecene	0.079
1-Pentadecene	0.052
1-Hexadecene	0.035
1-Heptadecene	0.024
1-Octadecene	0.016
1-Nonadecene	0.011
1-Eicosene	7.163E-003
Toluene	1.362
Ethylbenzene	0.863
N-Propylbenzene	0.560
1-butylbenzene	0.351
N-Pentylbenzene	0.222
N-Hexylbenzene	0.143
N-Heptylbenzene	0.091
N-Octylbenzene	0.059
N-Nonylbenzene	0.038
N-Dodecylbenzen	0.011

EQUIPMENT SUMMARIES

N-Decylbenzene	0.026
N-Undecylbenzen	0.017
Acetic Acid	1.802
Propionic Acid	1.142
N-Butyric Acid	0.739
Pentanoic Acid	0.439
N-Hexanoic Acid	0.281
Heptanoic Acid	0.183
N-Octanoic Acid	0.117
N-Nonanoic Acid	0.075
N-Decanoic Acid	0.048
undecanoic acid	0.033
Dodecanoic Acid	0.022
N-Tridecanoic A	0.015
N-Tetradecanoic	0.010
Pentadecanoic A	7.053E-003
N-Hexadecanoic	4.894E-003
Heptadecanoic A	3.442E-003
n-Octadecanoic	2.324E-003
Carbon	2.012E-008
Nitrogen	71.884

N-Heptylcyclope	0.143
Perylene	9.131E-004
pentacontane	7.827E-006
dopentacontane	6.030E-006
octatetracontan	1.003E-005
hexatetracontan	1.390E-005
tetratetraconta	1.957E-005
dotetracontane	2.488E-005
tetracontane	4.290E-005
octatriacontane	7.461E-005
tetratriacontan	2.226E-004
2-methyltetrade	0.061
Linolenic Acid	3.060E-003
Linoleic Acid	3.431E-003
Oleic Acid	2.818E-003
Benzene	2.281
O-Xylene	0.771
M-Xylene	0.827
P-Xylene	0.830
Indan	0.455
1-Methylindene	0.291
Naphthalene	0.238
1-Methylnaphtha	0.136
1-propylnaphtha	0.064
2,6-Dimethylnap	0.085
Sulfolane	0.097
Varsol	0.233

D-102: Flash 2

Flash Summary

Equip. No.	8
Name	
Flash Mode	6
Param 1	20.0000
Heat duty MJ/min	-0.8991
Type	1
Diameter ft	4.5000
Length ft	17.5812
Vessel thickness ft	0.0208
Head thickness ft	0.0208
Straight flange ft	0.1667
Metal density lb/ft3	489.0240

K values:

triolein	1.120
Water	84.533
Hydrogen	570.651
Carbon Monoxide	402.815
Carbon Dioxide	132.945
Methane	247.357
Ethane	73.932
n-Propane	35.844
N-Butane	17.452
N-Pentane	8.821

N-Hexane	4.527
N-Heptane	2.395
N-Octane	1.272
N-Nonane	0.676
N-Decane	0.369
N-Undecane	0.204
N-Dodecane	0.112
N-Tridecane	0.062
N-Tetradecane	0.034
N-Pentadecane	0.020
N-Hexadecane	0.011
N-Heptadecane	6.508E-003
N-Octadecane	4.194E-003
N-Nonadecane	2.695E-003
Eicosane	1.503E-003
uneicosane	7.866E-004
n-docosane	5.035E-004
n-tricosane	2.811E-004
n-Tetracosane	1.687E-004
n-pentacosane	1.063E-004
n-hexacosane	6.368E-005

N-Heptacosane	3.558E-005
n-Octacosane	2.529E-005
n-Nonacosane	1.744E-005
n-triacontane	1.108E-005
n-Dotriacontane	5.067E-006
n-Hexatriaconta	1.077E-006
2-Methyloctane	0.825
Cyclopentene	7.926
Methylcyclopent	4.253
Ethylcyclopenta	2.146
N-Propylcyclope	1.127
n-Butylcyclopen	0.605
N-Butylcyclohex	0.343
N-Hexylcyclo-C5	0.170
N-Octylcyclo-C5	0.052
N-Nonylcyclopen	0.028
N-Decylcyclopen	0.016
N-Decylcyclohex	8.523E-003
N-Dodecylcyclop	5.597E-003
N-Tridecylcyclo	3.427E-003
Ethylene	93.049
Propylene	39.525
1-Butene	19.423
1-Pentene	9.578
1-Hexene	4.930
1-Heptene	2.641
1-Octene	1.402
1-Nonene	0.751
1-Decene	0.408

1-Undecene	0.222
1-Dodecene	0.121
1-Tridecene	0.068
1-Tetradecene	0.038
1-Pentadecene	0.021
1-Hexadecene	0.012
1-Heptadecene	7.238E-003
1-Octadecene	4.200E-003
1-Nonadecene	2.345E-003
1-Eicosene	1.368E-003
Toluene	2.044
Ethylbenzene	1.101
N-Propylbenzene	0.610
1-butylbenzene	0.321
N-Pentylbenzene	0.171
N-Hexylbenzene	0.093
N-Heptylbenzene	0.050
N-Octylbenzene	0.027
N-Nonylbenzene	0.015

EQUIPMENT SUMMARIES

N-Dodecylbenzen	2.778E-003
N-Decylbenzene	8.361E-003
N-Undecylbenzen	4.538E-003
Acetic Acid	2.625
Propionic Acid	1.341
N-Butyric Acid	0.704
Pentanoic Acid	0.346
N-Hexanoic Acid	0.186
Heptanoic Acid	0.104
N-Octanoic Acid	0.057
N-Nonanoic Acid	0.032
N-Decanoic Acid	0.017
undecanoic acid	0.010
Dodecanoic Acid	5.779E-003
N-Tridecanoic A	3.122E-003
N-Tetradecanoic	1.970E-003
Pentadecanoic A	1.197E-003
N-Hexadecanoic	6.775E-004
Heptadecanoic A	4.256E-004
n-Octadecanoic	2.626E-004
Carbon	7.597E-011
Nitrogen	419.381
N-Heptylcyclope	0.092
Perylene	1.154E-004
pentacontane	1.889E-007
dopentacontane	1.372E-007
octatetracontan	2.552E-007
hexatetracontan	3.870E-007
tetratetraconta	5.973E-007
dotetracontane	7.844E-007
tetracontane	1.671E-006

octatriacontane	3.586E-006
tetratriacontan	1.601E-005
2-methyltetrade	0.028
Linolenic Acid	3.283E-004
Linoleic Acid	3.847E-004
Oleic Acid	2.942E-004
Benzene	4.137
O-Xylene	0.944
M-Xylene	1.024
P-Xylene	1.033
Indan	0.473
1-Methylindene	0.260
Naphthalene	0.203
1-Methylnaphtha	0.095
1-propylnaphtha	0.033
2,6-Dimethylnap	0.049
Sulfolane	0.059

Varsol	0.173

D-103: Flash 3

Flash Summary

Equip. No.	43
Name	
Flash Mode	6
Param 1	250.0000
Heat duty MJ/min	-0.6962
Type	1
Diameter ft	4.0000
Length ft	15.8430
Vessel thickness ft	0.0521
Head thickness ft	0.0521
Straight flange ft	0.1667
Metal density lb/ft3	489.0240

K values:

triolein	0.016
Water	7.906
Hydrogen	37.529
Carbon Monoxide	29.352
Carbon Dioxide	11.711
Methane	18.255
Ethane	6.965
n-Propane	3.783
N-Butane	2.062
N-Pentane	1.162
N-Hexane	0.662
N-Heptane	0.389
N-Octane	0.229

N-Nonane	0.135
N-Decane	0.081
N-Undecane	0.049
N-Dodecane	0.030
N-Tridecane	0.018
N-Tetradecane	0.011
N-Pentadecane	6.864E-003
N-Hexadecane	4.047E-003
N-Heptadecane	2.687E-003
N-Octadecane	1.831E-003
N-Nonadecane	1.254E-003
Eicosane	7.727E-004
uneicosane	4.524E-004
n-docosane	3.093E-004
n-tricosane	1.904E-004
n-Tetracosane	1.241E-004
n-pentacosane	8.405E-005
n-hexacosane	5.468E-005

N-Heptacosane	3.380E-005
n-Octacosane	2.516E-005
n-Nonacosane	1.834E-005
n-triacontane	1.251E-005
n-Dotriacontane	6.430E-006
n-Hexatriaconta	1.741E-006
2-Methyloctane	0.158
Cyclopentene	1.071
Methylcyclopent	0.624
Ethylcyclopenta	0.351
N-Propylcyclope	0.201
n-Butylcyclopen	0.121
N-Butylcyclohex	0.072
N-Hexylcyclo-C5	0.041
N-Octylcyclo-C5	0.015
N-Nonylcyclopen	9.059E-003
N-Decylcyclopen	5.623E-003
N-Decylcyclohex	3.353E-003
N-Dodecylcyclop	2.291E-003
N-Tridecylcyclo	1.492E-003
Ethylene	8.480
Propylene	4.119
1-Butene	2.281
1-Pentene	1.263
1-Hexene	0.714
1-Heptene	0.421
1-Octene	0.247
1-Nonene	0.146
1-Decene	0.087
1-Undecene	0.053
1-Dodecene	0.032
1-Tridecene	0.019

1-Tetradecene	0.012
1-Pentadecene	7.346E-003
1-Hexadecene	4.586E-003
1-Heptadecene	2.948E-003
1-Octadecene	1.854E-003
1-Nonadecene	1.139E-003
1-Eicosene	7.231E-004
Toluene	0.340
Ethylbenzene	0.201
N-Propylbenzene	0.122
1-butylbenzene	0.071
N-Pentylbenzene	0.042
N-Hexylbenzene	0.025
N-Heptylbenzene	0.015
N-Octylbenzene	9.027E-003
N-Nonylbenzene	5.375E-003

EQUIPMENT SUMMARIES

N-Dodecylbenzen	1.314E-003
N-Decylbenzene	3.354E-003
N-Undecylbenzen	2.022E-003
Acetic Acid	0.446
Propionic Acid	0.255
N-Butyric Acid	0.151
Pentanoic Acid	0.083
N-Hexanoic Acid	0.050
Heptanoic Acid	0.030
N-Octanoic Acid	0.018
N-Nonanoic Acid	0.011
N-Decanoic Acid	6.605E-003
undecanoic acid	4.238E-003
Dodecanoic Acid	2.656E-003
N-Tridecanoic A	1.629E-003
N-Tetradecanoic	1.071E-003
Pentadecanoic A	7.019E-004
N-Hexadecanoic	4.422E-004
Heptadecanoic A	2.960E-004
n-Octadecanoic	1.926E-004
Carbon	6.200E-010
Nitrogen	30.140
N-Heptylcyclope	0.025
Perylene	8.498E-005
pentacontane	3.035E-007
dopentacontane	2.270E-007
octatetracontan	3.999E-007
hexatetracontan	5.780E-007
tetratetraconta	8.506E-007
dotetracontane	1.108E-006
tetracontane	2.084E-006
octatriacontane	3.958E-006
tetratriacontan	1.399E-005
2-methyltetrade	9.054E-003
Linolenic Acid	2.475E-004

Linoleic Acid	2.817E-004
Oleic Acid	2.246E-004
Benzene	0.615
O-Xylene	0.177
M-Xylene	0.190
P-Xylene	0.191
Indan	0.098
1-Methylindene	0.059
Naphthalene	0.048
1-Methylnaphtha	0.025
1-propylnaphtha	0.011
2,6-Dimethylnap	0.015
Sulfolane	0.017

Varsol	0.043
Ethylene Glycol	0.188
Air	23.304
Oxygen	20.935

D-104: Flash 4

Flash Summary

Equip. No.	19
Name	
Flash Mode	6
Param 1	15.0000
Heat duty MJ/min	-1.7531
Type	1
Diameter ft	4.0000
Length ft	15.4435
Vessel thickness ft	0.0208
Head thickness ft	0.0208
Straight flange ft	0.1667
Metal density lb/ft3	489.0240

K values:	
triolein	0.080
Water	136.045
Hydrogen	641.145
Carbon Monoxide	489.275
Carbon Dioxide	184.671
Methane	297.552
Ethane	107.268
n-Propane	55.962
N-Butane	29.322
N-Pentane	15.866
N-Hexane	8.675
N-Heptane	4.907
N-Octane	2.773
N-Nonane	1.570

N-Decane	0.907
N-Undecane	0.531
N-Dodecane	0.307
N-Tridecane	0.180
N-Tetradecane	0.107
N-Pentadecane	0.064
N-Hexadecane	0.036
N-Heptadecane	0.023
N-Octadecane	0.015
N-Nonadecane	0.010
Eicosane	6.023E-003
uneicosane	3.378E-003
n-docosane	2.232E-003
n-tricosane	1.321E-003
n-Tetracosane	8.303E-004
n-pentacosane	5.444E-004
n-hexacosane	3.408E-004

EQUIPMENT SUMMARIES

N-Heptacosane	2.026E-004
n-Octacosane	1.464E-004
n-Nonacosane	1.037E-004
n-triacontane	6.842E-005
n-Dotriacontane	3.299E-005
n-Hexatriaconta	7.931E-006
2-Methyloctane	1.865
Cyclopentene	14.591
Methylcyclopent	8.257
Ethylcyclopenta	4.457
N-Propylcyclope	2.457
n-Butylcyclopen	1.424
N-Butylcyclohex	0.819
N-Hexylcyclo-C5	0.448
N-Octylcyclo-C5	0.153
N-Nonylcyclopen	0.087
N-Decylcyclopen	0.052
N-Decylcyclohex	0.030
N-Dodecylcyclop	0.019
N-Tridecylcyclo	0.012
Ethylene	131.851
Propylene	61.264
1-Butene	32.350
1-Pentene	17.314
1-Hexene	9.418
1-Heptene	5.354
1-Octene	3.017
1-Nonene	1.716
1-Decene	0.990
1-Undecene	0.574
1-Dodecene	0.334
1-Tridecene	0.197
1-Tetradecene	0.116

1-Pentadecene	0.069
1-Hexadecene	0.041
1-Heptadecene	0.026
1-Octadecene	0.016
1-Nonadecene	9.258E-003
1-Eicosene	5.666E-003
Toluene	4.332
Ethylbenzene	2.477
N-Propylbenzene	1.452
1-butylbenzene	0.815
N-Pentylbenzene	0.461
N-Hexylbenzene	0.266
N-Heptylbenzene	0.151
N-Octylbenzene	0.088
N-Nonylbenzene	0.051

N-Dodecylbenzen	0.011
N-Decylbenzene	0.030
N-Undecylbenzen	0.018
Acetic Acid	5.758
Propionic Acid	3.195
N-Butyric Acid	1.822
Pentanoic Acid	0.963
N-Hexanoic Acid	0.554
Heptanoic Acid	0.328
N-Octanoic Acid	0.190
N-Nonanoic Acid	0.111
N-Decanoic Acid	0.064
undecanoic acid	0.039
Dodecanoic Acid	0.024
N-Tridecanoic A	0.014
N-Tetradecanoic	8.966E-003
Pentadecanoic A	5.683E-003
N-Hexadecanoic	3.469E-003
Heptadecanoic A	2.249E-003
n-Octadecanoic	1.415E-003
Carbon	2.773E-009
Nitrogen	503.384
N-Heptylcyclope	0.257
Perylene	6.344E-004
pentacontane	1.178E-006
dopentacontane	8.556E-007
octatetracontan	1.599E-006
hexatetracontan	2.390E-006
tetratetraconta	3.649E-006
dotetracontane	4.919E-006
tetracontane	9.676E-006
octatriacontane	1.925E-005
tetratriacontan	7.474E-005
2-methyltetrade	0.085
Linolenic Acid	1.858E-003

Linoleic Acid	2.123E-003
Oleic Acid	1.666E-003
Benzene	8.168
O-Xylene	2.167
M-Xylene	2.331
P-Xylene	2.344
Indan	1.169
1-Methylindene	0.678
Naphthalene	0.547
1-Methylnaphtha	0.276
1-propylnaphtha	0.108
2,6-Dimethylnap	0.153
Sulfolane	0.187

Varsol	0.463
Ethylene Glycol	2.331
Air	385.281
Oxygen	344.551

D-105: Flash 5

Flash Summary

Equip. No.	46
Name	
Flash Mode	6
Param 1	15.0000
Heat duty MJ/min	-6.2597
Type	1
Diameter ft	4.5000
Length ft	6.3057
Vessel thickness ft	0.0208
Head thickness ft	0.0208
Straight flange ft	0.1667
Metal density lb/ft3	489.0240

K values:

triolein	4.643E+010
Water	21.607
Hydrogen	1118.715
Carbon Monoxide	588.190
Carbon Dioxide	65.411
Methane	207.581
Ethane	29.247
n-Propane	7.663
N-Butane	2.051
N-Pentane	0.592
N-Hexane	0.175
N-Heptane	0.053
N-Octane	0.017
N-Nonane	5.093E-003

N-Decane	1.731E-003
N-Undecane	5.740E-004
N-Dodecane	1.958E-004
N-Tridecane	6.274E-005
N-Tetradecane	2.147E-005
N-Pentadecane	7.777E-006
N-Hexadecane	2.732E-006
N-Heptadecane	1.184E-006
N-Octadecane	5.729E-007
N-Nonadecane	2.758E-007
Eicosane	8.803E-008
uneicosane	2.444E-008
n-docosane	1.152E-008
n-tricosane	3.754E-009
n-Tetracosane	1.467E-009
n-pentacosane	6.375E-010
n-hexacosane	2.497E-010

N-Heptacosane	7.895E-011
n-Octacosane	4.665E-011
n-Nonacosane	2.480E-011
n-triacontane	1.094E-011
n-Dotriacontane	2.910E-012
n-Hexatriaconta	1.842E-013
2-Methyloctane	7.892E-003
Cyclopentene	0.477
Methylcyclopent	0.164
Ethylcyclopenta	0.048
N-Propylcyclope	0.017
n-Butylcyclopen	4.628E-003
N-Butylcyclohex	2.667E-003
N-Hexylcyclo-C5	4.648E-004
N-Octylcyclo-C5	5.635E-005
N-Nonylcyclopen	1.855E-005
N-Decylcyclopen	6.920E-006
N-Decylcyclohex	1.939E-006
N-Dodecylcyclop	1.279E-006
N-Tridecylcyclo	5.880E-007
Ethylene	43.921
Propylene	8.957
1-Butene	2.453
1-Pentene	0.590
1-Hexene	0.198
1-Heptene	0.065
1-Octene	0.021
1-Nonene	6.693E-003
1-Decene	2.144E-003
1-Undecene	6.741E-004
1-Dodecene	2.066E-004
1-Tridecene	7.579E-005
1-Tetradecene	2.662E-005

1-Pentadecene	9.331E-006
1-Hexadecene	3.384E-006
1-Heptadecene	1.362E-006
1-Octadecene	5.023E-007
1-Nonadecene	1.683E-007
1-Eicosene	6.356E-008
Toluene	0.040
Ethylbenzene	0.013
N-Propylbenzene	4.485E-003
1-butylbenzene	1.357E-003
N-Pentylbenzene	4.307E-004
N-Hexylbenzene	1.439E-004
N-Heptylbenzene	4.499E-005
N-Octylbenzene	1.509E-005
N-Nonylbenzene	4.301E-006

N-Dodecylbenzen	2.326E-007
N-Decylbenzene	1.535E-006
N-Undecylbenzen	4.635E-007
Acetic Acid	0.035
Propionic Acid	8.490E-003
N-Butyric Acid	2.119E-003
Pentanoic Acid	5.786E-004
N-Hexanoic Acid	1.746E-004
Heptanoic Acid	5.968E-005
N-Octanoic Acid	2.050E-005
N-Nonanoic Acid	7.566E-006
N-Decanoic Acid	2.509E-006
undecanoic acid	9.341E-007
Dodecanoic Acid	3.305E-007
N-Tridecanoic A	7.867E-008
N-Tetradecanoic	4.816E-008
Pentadecanoic A	2.024E-008
N-Hexadecanoic	5.564E-009
Heptadecanoic A	2.656E-009
n-Octadecanoic	1.430E-009
Carbon	1.000E-020
Nitrogen	687.356
N-Heptylcyclope	1.611E-004
Perylene	1.105E-009
pentacontane	1.750E-013
dopentacontane	1.251E-013
octatetracontan	2.327E-013
hexatetracontan	4.055E-013
tetratetraconta	7.024E-013
dotetracontane	7.712E-013
tetracontane	3.227E-012
octatriacontane	1.327E-011
tetratriacontan	1.969E-010
2-methyltetrade	2.084E-005
Linolenic Acid	1.072E-009

Linoleic Acid	1.514E-009
Oleic Acid	9.312E-010
Benzene	0.149
O-Xylene	9.621E-003
M-Xylene	0.011
P-Xylene	0.011
Indan	2.787E-003
1-Methylindene	9.906E-004
Naphthalene	6.407E-004
1-Methylnaphtha	1.635E-004
1-propylnaphtha	2.064E-005
2,6-Dimethylnap	4.387E-005
Sulfolane	5.025E-005

Varsol	4.122E-004
Ethylene Glycol	4.874E-003
Air	414.930
Oxygen	308.166

D-107: Acetic Flash 1

Three Phase Flash Summary

Equip. No.	39
Name	
Flash Mode	1
Param1	420.0000
Param2	200.0000
Heat duty MJ/min	-25.8485

D-108: Acetic Flash 2

Three Phase Flash Summary

Equip. No.	65
Name	
Flash Mode	1
Param1	146.0000
Param2	30.0000
Heat duty MJ/min	18.7536

D-109: Flash 7

Flash Summary

Equip. No.	6
Name	
Flash Mode	6
Param 1	25.0000
Heat duty MJ/min	-1.6402

K values:	
triolein	1639.891
Water	42.106
Hydrogen	467.352
Carbon Monoxide	343.063
Carbon Dioxide	75.651
Methane	153.196
Ethane	37.841
n-Propane	14.408
N-Butane	5.558
N-Pentane	2.249
N-Hexane	0.923
N-Heptane	0.392
N-Octane	0.170
N-Nonane	0.073
N-Decane	0.033
N-Undecane	0.015
N-Dodecane	6.735E-003
N-Tridecane	3.006E-003
N-Tetradecane	1.385E-003
N-Pentadecane	6.566E-004
N-Hexadecane	2.960E-004
N-Heptadecane	1.583E-004
N-Octadecane	9.045E-005
N-Nonadecane	5.150E-005
Eicosane	2.309E-005
uneicosane	9.443E-006
n-docosane	5.320E-006
n-tricosane	2.404E-006
n-Tetracosane	1.215E-006
n-pentacosane	6.589E-007
n-hexacosane	3.326E-007
N-Heptacosane	1.489E-007
n-Octacosane	9.740E-008
n-Nonacosane	6.026E-008
n-triacontane	3.302E-008
n-Dotriacontane	1.202E-008
n-Hexatriaconta	1.557E-009
2-Methyloctane	0.097

EQUIPMENT SUMMARIES

Cyclopentene	1.950
Methylcyclopent	0.872
Ethylcyclopenta	0.355
N-Propylcyclope	0.159
n-Butylcyclopen	0.066
N-Butylcyclohex	0.037
N-Hexylcyclo-C5	0.012
N-Octylcyclo-C5	2.585E-003
N-Nonylcyclopen	1.139E-003
N-Decylcyclopen	5.458E-004

N-Decylcyclohex	2.299E-004
N-Dodecylcyclop	1.457E-004
N-Tridecylcyclo	7.875E-005
Ethylene	51.272
Propylene	16.243
1-Butene	6.350
1-Pentene	2.377
1-Hexene	1.027
1-Heptene	0.453
1-Octene	0.196
1-Nonene	0.086
1-Decene	0.038
1-Undecene	0.017
1-Dodecene	7.271E-003
1-Tridecene	3.435E-003
1-Tetradecene	1.596E-003
1-Pentadecene	7.430E-004
1-Hexadecene	3.540E-004
1-Heptadecene	1.796E-004
1-Octadecene	8.703E-005
1-Nonadecene	3.972E-005
1-Eicosene	1.946E-005
Toluene	0.327
Ethylbenzene	0.143
N-Propylbenzene	0.066
1-butylbenzene	0.028
N-Pentylbenzene	0.012
N-Hexylbenzene	5.420E-003
N-Heptylbenzene	2.344E-003
N-Octylbenzene	1.062E-003
N-Nonylbenzene	4.447E-004
N-Dodecylbenzen	5.078E-005
N-Decylbenzene	2.105E-004
N-Undecylbenzen	9.099E-005
Acetic Acid	0.371
Propionic Acid	0.143
N-Butyric Acid	0.056
Pentanoic Acid	0.022

N-Hexanoic Acid	9.481E-003
Heptanoic Acid	4.364E-003
N-Octanoic Acid	1.989E-003
N-Nonanoic Acid	9.343E-004
N-Decanoic Acid	4.169E-004
undecanoic acid	2.047E-004
Dodecanoic Acid	9.696E-005
N-Tridecanoic A	3.851E-005
N-Tetradecanoic	2.351E-005
Pentadecanoic A	1.231E-005
N-Hexadecanoic	5.301E-006
Heptadecanoic A	2.964E-006

n-Octadecanoic	1.705E-006
Carbon	3.771E-015
Nitrogen	376.349
N-Heptylcyclope	5.546E-003
Perylene	9.042E-007
pentacontane	4.352E-010
dopentacontane	3.083E-010
octatetracontan	5.963E-010
hexatetracontan	9.703E-010
tetratetraconta	1.598E-009
dotetracontane	2.018E-009
tetracontane	5.591E-009
octatriacontane	1.550E-008
tetratriacontan	1.116E-007
2-methyltetrade	1.182E-003
Linolenic Acid	1.816E-006
Linoleic Acid	2.278E-006
Oleic Acid	1.598E-006
Benzene	0.843
O-Xylene	0.116
M-Xylene	0.128
P-Xylene	0.130
Indan	0.047
1-Methylindene	0.022
Naphthalene	0.016
1-Methylnaphtha	5.829E-003
1-propylnaphtha	1.369E-003
2,6-Dimethylnap	2.330E-003
Sulfolane	2.815E-003
Varsol	0.012
Ethylene Glycol	0.093
Air	253.776
Oxygen	209.257

H.3.iii. Heat Exchangers

E-201 A/B: Post Cracking Cooler

Heat Exchanger Summary

Equip. No.	2
Name	
1st Stream dp psi	5.0000
2nd Stream dp psi	5.0000
1st Stream T Out F	439.0000
U Btu/hr-ft2-F	700.0000
Calc Ht Duty MJ/min	690.1989
LMTD (End points) F	287.9161
LMTD Corr Factor	1.0000
Calc U Btu/hr-ft2-F	700.0000
Calc Area ft2	194.7531
1st Stream Pout psia	255.0000
2nd Stream Pout psia	15.0000
P1 out specifed psia	255.0000
P2 out specifed psia	15.0000

E-202 A/B: Flash 2 Cooler

```
Heat Exchanger Summary

Equip. No.                        9
       Name
1st Stream dp  psi           5.0000
2nd Stream dp  psi           5.0000
1st Stream T Out  F        300.0000
2nd Stream VF Out            1.0000
Calc Ht Duty  MJ/min       130.7119
LMTD (End points)  F       172.6354
LMTD Corr Factor             1.0000
Utility Option:                 1
1st Stream Pout  psia       95.0000
2nd Stream Pout  psia       50.0000
P1 out specifed  psia       95.0000
P2 out specifed  psia       50.0000
```

E-204 A/B: Syngas Cooler

```
Heat Exchanger Summary

Equip. No.                       37
       Name
1st Stream dp  psi           5.0000
2nd Stream dp  psi           5.0000
1st Stream T Out  F         90.0000
2nd Stream T Out  F        113.0000
Calc Ht Duty  MJ/min       149.3825
LMTD (End points)  F       100.4398
LMTD Corr Factor             1.0000
Utility Option:                 1
1st Stream Pout  psia      455.0000
2nd Stream Pout  psia       50.0000
P1 out specifed  psia      455.0000
P2 out specifed  psia       50.0000
```

E-205 A/B: Debutanizer Cooler

```
Heat Exchanger Summary

Equip. No.                       71
       Name
1st Stream dp  psi           5.0000
1st Stream T Out  F        250.0000
Calc Ht Duty  MJ/min       -17.2797
LMTD Corr Factor             1.0000
1st Stream Pout  psia      395.0000
P1 out specifed  psia      395.0000
```

E-207 A/B: Pre-Flash 5 Cooler

```
Heat Exchanger Summary
```

```
Equip. No.                     67
       Name
1st Stream dp  psi           5.0000
2nd Stream dp  psi           5.0000
1st Stream T Out  F        100.0000
2nd Stream T Out  F        113.0000
Calc Ht Duty  MJ/min        19.4297
LMTD (End points)  F        34.7452
LMTD Corr Factor             1.0000
Utility Option:                1
1st Stream Pout  psia       25.0000
2nd Stream Pout  psia       50.0000
P1 out specifed  psia       25.0000
P2 out specifed  psia       50.0000
```

E-208 A/B: Post Diesel Decarbox Cooler

```
Heat Exchanger Summary

Equip. No.                     27
       Name
1st Stream dp  psi           5.0000
2nd Stream dp  psi           5.0000
1st Stream T Out  F        350.0000
2nd Stream T Out  F        113.0000
Calc Ht Duty  MJ/min       134.9829
LMTD (End points)  F       367.4783
LMTD Corr Factor             1.0000
Utility Option:                1
1st Stream Pout  psia      315.0000
2nd Stream Pout  psia       50.0000
P1 out specifed  psia      315.0000
P2 out specifed  psia       50.0000
```

E-209 A/B: Post Naphtha Decarbox Cooler

```
Heat Exchanger Summary

Equip. No.                     40
       Name
1st Stream dp  psi           5.0000
2nd Stream dp  psi           5.0000
1st Stream T Out  F        200.0000
2nd Stream T Out  F        113.0000
Calc Ht Duty  MJ/min       174.8056
LMTD (End points)  F       259.4733
LMTD Corr Factor             1.0000
Utility Option:                1
1st Stream Pout  psia      315.0000
2nd Stream Pout  psia       50.0000
P1 out specifed  psia      315.0000
P2 out specifed  psia       50.0000
```

E-210 A/B: Interstage Cooler 1

Heat Exchanger Summary

Equip. No.	82
Name	
1st Stream dp psi	5.0000
2nd Stream dp psi	5.0000
1st Stream T Out F	125.0000
2nd Stream T Out F	113.0000
Calc Ht Duty MJ/min	32.4602
LMTD (End points) F	89.0485
LMTD Corr Factor	1.0000
Utility Option:	1
1st Stream Pout psia	55.0000
2nd Stream Pout psia	50.0000
P1 out specifed psia	55.0000
P2 out specifed psia	50.0000

E-211 A/B: Interstage Cooler 2

Heat Exchanger Summary

Equip. No.	83
Name	
1st Stream dp psi	5.0000
2nd Stream dp psi	5.0000
1st Stream T Out F	190.0000
2nd Stream T Out F	113.0000
Calc Ht Duty MJ/min	38.1071
LMTD (End points) F	164.6077
LMTD Corr Factor	1.0000
Utility Option:	1
1st Stream Pout psia	215.0000
2nd Stream Pout psia	50.0000
P1 out specifed psia	215.0000
P2 out specifed psia	50.0000

E-212 A/B: Naphtha Cooler

Heat Exchanger Summary

Equip. No.	30
Name	
1st Stream dp psi	1.0000
1st Stream T Out F	130.0000
Calc Ht Duty MJ/min	-9.9132
LMTD Corr Factor	1.0000
1st Stream Pout psia	17.0000
P1 out specifed psia	17.0000

E-213 A/B: Jet Cooler

Heat Exchanger Summary

```
Equip. No.                    73
       Name
1st Stream dp  psi          5.0000
1st Stream T Out  F       130.0000
Calc Ht Duty  MJ/min      -46.8746
LMTD Corr Factor            1.0000
1st Stream Pout  psia      10.0000
P1 out specifed  psia      10.0000
```

E-214 A/B: Diesel Cooler

```
Heat Exchanger Summary

Equip. No.                    86
       Name
1st Stream dp  psi          5.0000
1st Stream T Out  F       130.0000
Calc Ht Duty  MJ/min     -148.2123
LMTD Corr Factor            1.0000
1st Stream Pout  psia      15.0000
P1 out specifed  psia      15.0000
```

E-215 A/B: Fuel Oil Cooler

```
   Heat Exchanger Summary

Equip. No.                    87
       Name
1st Stream dp  psi          5.0000
1st Stream T Out  F       104.0000
Calc Ht Duty  MJ/min       -3.9909
LMTD Corr Factor            1.0000
1st Stream Pout  psia      25.0000
P1 out specifed  psia      25.0000
```

E-502 A/B: TTCR Preheat

```
Heat Exchanger Summary

Equip. No.                    74
       Name
1st Stream dp  psi          5.0000
2nd Stream dp  psi          5.0000
1st Stream T Out  F       770.0001
2nd Stream T Out  F       700.0001
Calc Ht Duty  MJ/min      303.2726
LMTD (End points)  F       72.7786
LMTD Corr Factor            1.0000
Utility Option:                1
1st Stream Pout  psia     275.0000
2nd Stream Pout  psia     870.0000
P1 out specifed  psia     275.0000
P2 out specifed  psia     870.0000
```

E-503 A/B: Naphtha Decarbox Heater

```
Heat Exchanger Summary

Equip. No.                      17
       Name
1st Stream dp  psi            5.0000
1st Stream T Out  F         608.0001
Calc Ht Duty  MJ/min        176.6798
LMTD Corr Factor              1.0000
1st Stream Pout  psia       345.0000
P1 out specifed  psia       345.0000
```

E-504 A/B: Diesel Decarbox Heater

```
Heat Exchanger Summary

Equip. No.                      24
       Name
1st Stream dp  psi            5.0000
1st Stream T Out  F         608.0001
Calc Ht Duty  MJ/min         86.5038
LMTD Corr Factor              1.0000
1st Stream Pout  psia       345.0000
P1 out specifed  psia       345.0000
```

E-505 A/B: Pre Jet Diesel Cut Heat

```
Heat Exchanger Summary

Equip. No.                      68
       Name
1st Stream dp  psi            5.0000
2nd Stream dp  psi            5.0000
1st Stream T Out  F         400.0000
2nd Stream VF Out        1.0000e-005
Calc Ht Duty  MJ/min         25.6697
LMTD (End points)  F         88.4139
LMTD Corr Factor              1.0000
Utility Option:                  1
1st Stream Pout  psia        25.0000
2nd Stream Pout  psia       473.0000
P1 out specifed  psia        25.0000
P2 out specifed  psia       473.0000
```

H.3.iv. Compressors

G-101 A/B Flash 2 Compressor

```
   Compressor Summary

Equip. No.                      12
       Name
Pressure out  psia           60.0000
Type of Compressor               1
```

```
Efficiency                     0.5500
Actual power  MJ/min           1.0062
Cp/Cv                          1.0739
Theoretical power              0.5534
 (MJ/min)
Ideal Cp/Cv                    1.0686
Calc Pout  psia               60.0000
Calc. mass flowrate              20
 (lb/min)
```

G-103 A/B: Flash 5 Compressor

```
  Compressor Summary

Equip. No.                       21
       Name
Pressure out  psia            35.0000
Type of Compressor                1
Efficiency                     0.5500
Actual power  MJ/min           0.9004
Cp/Cv                          1.0779
Theoretical power              0.4952
 (MJ/min)
Ideal Cp/Cv                    1.0750
Calc Pout  psia               35.0000
Calc. mass flowrate              23
 (lb/min)
```

G-105 Stage 1: Light End Compressor

```
  Compressor Summary

Equip. No.                       79
       Name
Pressure out  psia            60.0000
Type of Compressor                1
Efficiency                     0.5500
Actual power  MJ/min          40.5066
Cp/Cv                          1.1881
Theoretical power             22.2786
 (MJ/min)
Ideal Cp/Cv                    1.1813
Calc Pout  psia               60.0000
Calc. mass flowrate               539
 (lb/min)
```

G-105 Stage 2: Light End Compressor

```
  Compressor Summary

Equip. No.                       80
       Name
Pressure out  psia           220.0000
Type of Compressor                1
Efficiency                     0.5000
```

Actual power MJ/min	47.5165
Cp/Cv	1.1870
Theoretical power (MJ/min)	23.7583
Ideal Cp/Cv	1.1682
Calc Pout psia	220.0000
Calc. mass flowrate (lb/min)	539

G-105 Stage 3: Light End Compressor

Compressor Summary

Equip. No.	81
Name	
Pressure out psia	460.0000
Type of Compressor	1
Efficiency	0.5500
Actual power MJ/min	23.9785
Cp/Cv	1.2053
Theoretical power (MJ/min)	13.1882
Ideal Cp/Cv	1.1498
Calc Pout psia	460.0000
Calc. mass flowrate (lb/min)	539

H.3.v. Pumps

L-102 A/B: PreCracking Pump

Pump Summary

Equip. No.	3	4
Name		
Output pressure psia	40.0000	280.0000
Efficiency	0.6500	0.6500
Calculated power (MJ/min)	0.3893	3.8936
Calculated Pout psia	40.0000	280.0000
Head ft	84.7726	847.8664
Vol. flow rate (ft3/min)	51.8054	51.8141
Mass flow rate lb/min	2200.0000	2200.0000

L-103 A/B: Pre Naphtha Pump

Pump Summary

Equip. No.	16
Name	
Output pressure psia	350.0000
Efficiency	0.6500
Calculated power (MJ/min)	1.0396

```
Calculated Pout  psia      350.0000
Head  ft                  1010.7957
Vol. flow rate              10.3242
 (ft3/min)
Mass flow rate  lb/min     492.7206
```

L-104 A/B: Atmospheric Reflux

```
Pump Summary

Equip. No.                    92
       Name
Output pressure  psia       18.0000
Efficiency                   0.6500
Calculated power             0.0076
 (MJ/min)
Calculated Pout  psia       18.0000
Head  ft                     9.0509
Vol. flow rate               8.4224
 (ft3/min)
Mass flow rate  lb/min     402.0000
```

L-105 A/B: Atmospheric Bottoms

```
Pump Summary

Equip. No.                    93
       Name
Output pressure  psia       20.0000
Efficiency                   0.6500
Calculated power             0.0398
 (MJ/min)
Calculated Pout  psia       20.0000
Head  ft                    14.5066
Vol. flow rate              33.1129
 (ft3/min)
Mass flow rate  lb/min    1314.7838
```

L-106 A/B: Vacuum Column Bottoms

```
Pump Summary

Equip. No.                    95
       Name
Output pressure  psia       25.0000
Efficiency                   0.6500
Calculated power             0.0454
 (MJ/min)
Calculated Pout  psia       25.0000
Head  ft                    35.2290
Vol. flow rate              15.0982
 (ft3/min)
Mass flow rate  lb/min     617.1440
```

L-107 A/B: Vacuum Bottoms

```
Pump Summary

Equip. No.                       96
       Name
Output pressure  psia       18.0000
Efficiency                   0.6500
Calculated power             0.0353
 (MJ/min)
Calculated Pout  psia       18.0000
Head  ft                    10.3308
Vol. flow rate              39.1469
 (ft3/min)
Mass flow rate  lb/min    1637.0004
```

L-108 A/B: Vacuum Reflux

```
Pump Summary

Equip. No.                       94
       Name
Output pressure  psia       20.0000
Efficiency                   0.6500
Calculated power             0.2574
 (MJ/min)
Calculated Pout  psia       20.0000
Head  ft                    55.4283
Vol. flow rate              53.5278
 (ft3/min)
Mass flow rate  lb/min    2225.0005
```

L-109 A/B: PreDiesel Decarbox

```
Pump Summary

Equip. No.                       23
       Name
Output pressure  psia      350.0000
Efficiency                   0.6500
Calculated power             1.7352
 (MJ/min)
Calculated Pout  psia      350.0000
Head  ft                  1191.5531
Vol. flow rate              16.6846
 (ft3/min)
Mass flow rate  lb/min     697.6542
```

L-110 A/B: Pre Jet-Diesel Cut Heat Pump

```
Pump Summary

Equip. No.                       20
       Name
Output pressure  psia       30.0000
```

```
Efficiency                      0.6500
Calculated power                0.0682
 (MJ/min)
Calculated Pout  psia          30.0000
Head  ft                       50.7793
Vol. flow rate                 15.1289
 (ft3/min)
Mass flow rate  lb/min        643.5379
```

L-111 A/B: Naphtha Product

```
Pump Summary

Equip. No.                        59
       Name
Output pressure  psia          25.0000
Efficiency                      0.6500
Calculated power                0.0083
 (MJ/min)
Calculated Pout  psia          25.0000
Head  ft                       26.7200
Vol. flow rate                  3.4385
 (ft3/min)
Mass flow rate  lb/min        148.2460
```

L-112 A/B: Jet Diesel Cut Reflux

```
Pump Summary

Equip. No.                        97
       Name
Output pressure  psia          19.0000
Efficiency                      0.6500
Calculated power                0.0245
 (MJ/min)
Calculated Pout  psia          19.0000
Head  ft                       14.4126
Vol. flow rate                 20.3927
 (ft3/min)
Mass flow rate  lb/min        814.9983
```

L-113 A/B: Jet Diesel Cut Bottoms

```
Pump Summary

Equip. No.                        98
       Name
Output pressure  psia          25.0000
Efficiency                      0.6500
Calculated power                0.0518
 (MJ/min)
Calculated Pout  psia          25.0000
Head  ft                       31.2828
Vol. flow rate                 21.5541
 (ft3/min)
```

```
Mass flow rate  lb/min     793.7383
```

L-114 A/B: Diesel Fuel Oil Cut Reflux

```
Equip. No.                      99
       Name
Output pressure  psia       25.0000
Efficiency                   0.6500
Calculated power             0.0487
 (MJ/min)
Calculated Pout  psia       25.0000
Head  ft                    20.1622
Vol. flow rate              32.4275
 (ft3/min)
Mass flow rate  lb/min    1158.0001
```

L-115 A/B: Diesel Fuel Oil Cut Bottoms

```
Pump Summary

Equip. No.                     100
       Name
Output pressure  psia       40.0000
Efficiency                   0.6500
Calculated power             0.0137
 (MJ/min)
Calculated Pout  psia       40.0000
Head  ft                    45.5084
Vol. flow rate               4.5721
 (ft3/min)
Mass flow rate  lb/min     144.6715
```

L-116 A/B: Flash 5 Pump

```
Pump Summary

Equip. No.                      69
       Name
Output pressure  psia       25.0000
Efficiency                   0.6500
Calculated power             0.0029
 (MJ/min)
Calculated Pout  psia       25.0000
Head  ft                    31.5281
Vol. flow rate               0.9725
 (ft3/min)
Mass flow rate  lb/min      44.4162
```

L-117 A/B: Hexane Splitter Reflux

```
Pump Summary

Equip. No.                      75
       Name
Output pressure  psia       25.0000
```

```
Efficiency                    0.6500
Calculated power              0.0016
 (MJ/min)
Calculated Pout  psia        25.0000
Head  ft                     51.8551
Vol. flow rate                0.3511
 (ft3/min)
Mass flow rate  lb/min       14.6234
```

L-118 A/B: Jet Fuel Product

```
Pump Summary

Equip. No.                      61
       Name
Output pressure  psia        25.0000
Efficiency                    0.6500
Calculated power              0.0289
 (MJ/min)
Calculated Pout  psia        25.0000
Head  ft                     31.7550
Vol. flow rate                8.7534
 (ft3/min)
Mass flow rate  lb/min      436.6364
```

L-119 A/B: Naphtha Jet Reflux

```
Pump Summary

Equip. No.                      77
       Name
Output pressure  psia        18.0000
Efficiency                    0.6500
Calculated power              0.0038
 (MJ/min)
Calculated Pout  psia        18.0000
Head  ft                     17.4987
Vol. flow rate                2.5153
 (ft3/min)
Mass flow rate  lb/min      103.4960
```

L-120 A/B: Naphtha Jet Bottoms

```
Equip. No.                     103
       Name
Output pressure  psia        28.0000
Efficiency                    0.6500
Calculated power              0.0414
 (MJ/min)
Calculated Pout  psia        28.0000
Head  ft                     49.3811
Vol. flow rate               10.5882
 (ft3/min)
Mass flow rate  lb/min      401.3890
```

L-121 A/B: Debutanizer Reflux

```
Equip. No.                      101
       Name
Output pressure  psia      120.0000
Efficiency                   0.6500
Calculated power             0.0132
 (MJ/min)
Calculated Pout  psia      120.0000
Head  ft                    43.2041
Vol. flow rate               4.3825
 (ft3/min)
Mass flow rate  lb/min     146.0695
```

L-124 A/B: C5 Bottoms

```
Equip. No.                      107
       Name
Output pressure  psia       28.0000
Efficiency                   0.6500
Calculated power             0.0073
 (MJ/min)
Calculated Pout  psia       28.0000
Head  ft                    29.2481
Vol. flow rate               3.0220
 (ft3/min)
Mass flow rate  lb/min     119.0281
```

L-125 A/B: C5 Reflux

```
   Pump Summary

Equip. No.                      106
       Name
Output pressure  psia       25.0000
Efficiency                   0.6500
Calculated power             0.0094
 (MJ/min)
Calculated Pout  psia       25.0000
Head  ft                    18.3392
Vol. flow rate               6.2404
 (ft3/min)
Mass flow rate  lb/min     245.0000
```

L-126 A/B: Hexane Splitter Reflux

```
   Pump Summary

Equip. No.                       75
       Name
Output pressure  psia       25.0000
Efficiency                   0.6500
Calculated power             0.0016
 (MJ/min)
Calculated Pout  psia       25.0000
```

```
Head  ft                    51.8551
Vol. flow rate               0.3511
 (ft3/min)
Mass flow rate  lb/min      14.6234
```

L-127 A/B: Syngas Column Reflux

```
Pump Summary

Equip. No.                       72
       Name
Output pressure  psia      470.0000
Efficiency                   0.6500
Calculated power             0.0152
 (MJ/min)
Calculated Pout  psia      470.0000
Head  ft                    27.1590
Vol. flow rate              10.1120
 (ft3/min)
Mass flow rate  lb/min     268.0757
```

Appendix I. Drawings and Tables in English Units

Table I.1. Equipment lettering system [47].

Letter	Definition
C	Crushers
D	Process (Pressure) Vessels
E	Heat Exchangers
F	Storage Vessels
G	Gas Movers
J	Solids Conveyors
L	Pumps
P	Package Units
Q	Furnaces
R	Reactors

Table I.2. Equipment number codes and corresponding definitions.

Code	Definition
C-100 Series	Crushers Base Designs/Carbon Fiber
D-100 Series	Flash Drums Base Designs/Carbon Fiber
D-200 Series	Distillation Columns Base Designs/Carbon Fiber
D-300 Series	Reflux Drums Base Designs/Carbon Fiber
E-100 Series	Column Condensers Base Designs/Carbon Fiber
E-200 Series	Cooler Heat Exchangers Base Designs/Carbon Fiber
E-400 Series	Column Reboilers Base Designs/Carbon Fiber
E-500 Series	Heater Heat Exchangers Base Designs/Carbon Fiber
D-500 Series	Knockout Drums Base Designs/Carbon Fiber
G-100 Series	Compressors Base Designs/Carbon Fiber
J-100 Series	Solid Conveyors Base Designs/Carbon Fiber
L-100 Series	Pumps Base Designs/Carbon Fiber
P-100 Series	Refrigeration Unit Base Designs/Carbon Fiber
Q-100 Series	Boilers Base Designs/Carbon Fiber
R-100 Series	Reactors Base Designs/Carbon Fiber
D-600 Series	Flash Drums Fatty Acid Design
D-700 Series	Distillation Columns Fatty Acid Design
D-800 Series	Reflux Drums Fatty Acid Design
D-900 Series	Extractor Fatty Acid Design
E-600 Series	Column Condensers Fatty Acid Design
E-700 Series	Cooler Heat Exchangers Fatty Acid Design
E-900 Series	Column Reboilers Fatty Acid Design
E-800 Series	Heater Heat Exchangers Fatty Acid Design
E-1000 Series	Product Coolers Fatty Acid Design
F-200 Series	Knockout Drums Fatty Acid Design
G-200 Series	Compressors Fatty Acid Design
L-200 Series	Pumps Fatty Acid Design
P-200 Series	Refrigeration Unit Fatty Acid Design
Q-200 Series	Boilers Fatty Acid Design
R-200 Series	Reactors Fatty Acid Design
E-1100 Series	Product Coolers Base Design/Carbon Fiber Design
1##	Unit Number
A	Equipment 1 for redundant equipment

Table I.3. Equipment naming system using example number D-101 A.

Code	D	100 Series	101	A
Definition	Pressure Vessels	Flash Drum	First Unit	Equipment piece 1 of 2

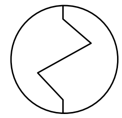
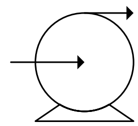
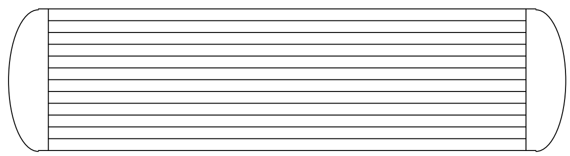
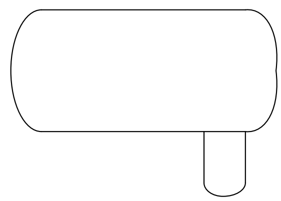
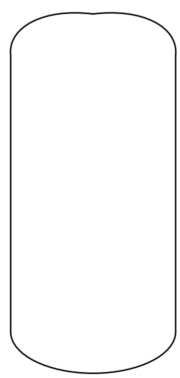
Table I.4. Drawing naming system using example number 00-A-001/1.

Code	00	A	001	/1
Definition	Plant Section	Drawing Size	Drawing Type	Sheet

Table I.5. Drawing number codes for English Units and corresponding definitions.

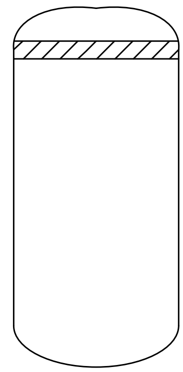
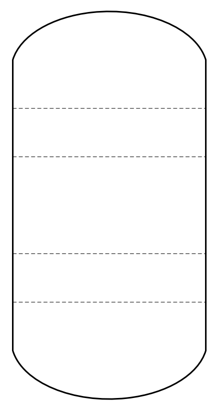
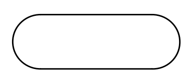
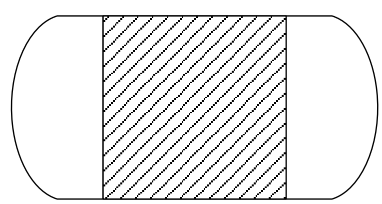
Code	Definition
00	Entire Plant
01	Thermal Cracking Section
02	Purification Section
03	Decarboxylation Section
04	Trim Purification Section
05	Light End Processing
06	Tar Processing
07	Fatty Acid Recovery Section
A	11x17" Drawing Size
001	Alternative Base Design Input/Output Diagram - English Units
002	Alternative Base Design Block Flow Diagram - English Units
003	Alternative Base Design Process Flow Diagram - English Units
004	Fatty Acid Alternative Input/Output Diagram - English Units
005	Fatty Acid Alternative Block Flow Diagram – English Units
006	Fatty Acid Alternative Process Flow Diagram – English Units
013	Carbon Fiber Recovery Input/Output Diagram – English Units
014	Carbon Fiber Recovery Block Flow Diagram – English Units
015	Carbon Fiber Recovery Process Flow Diagram – English Units
019	Base Design Input/Output Diagram – English Units
020	Base Design Block Flow Diagram – Engligh Units
021	Base Design Process Flow Diagram – Engligh Units

Table I.6. Example equipment used in drawings.

Equipment	Symbol
Heat Exchanger	
Pump	
Turbulent Tubular Cracking Reactor (TTCR)	
Three Phase Flash Drum	
Two Phase Flash Drum	

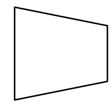
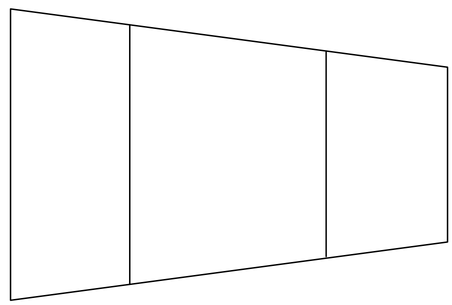
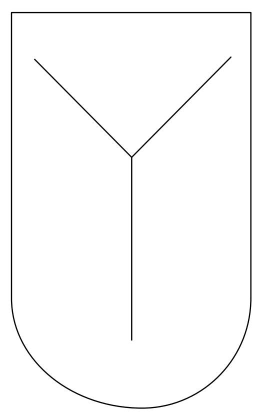
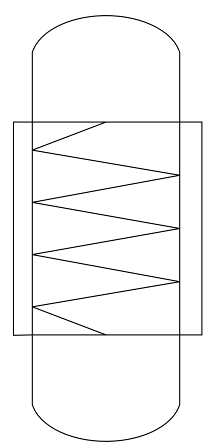
(continued)

Table I.6. Cont.

Equipment	Symbol
Flash Drum with Mist Pad	
Distillation Column	
Reflux Drum	
Decarboxylation Reactor	

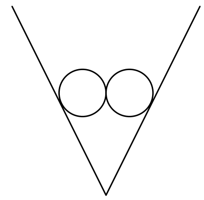
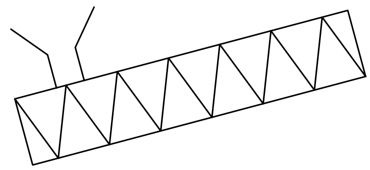
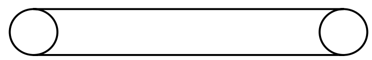
(continued)

Table I.6. Cont.

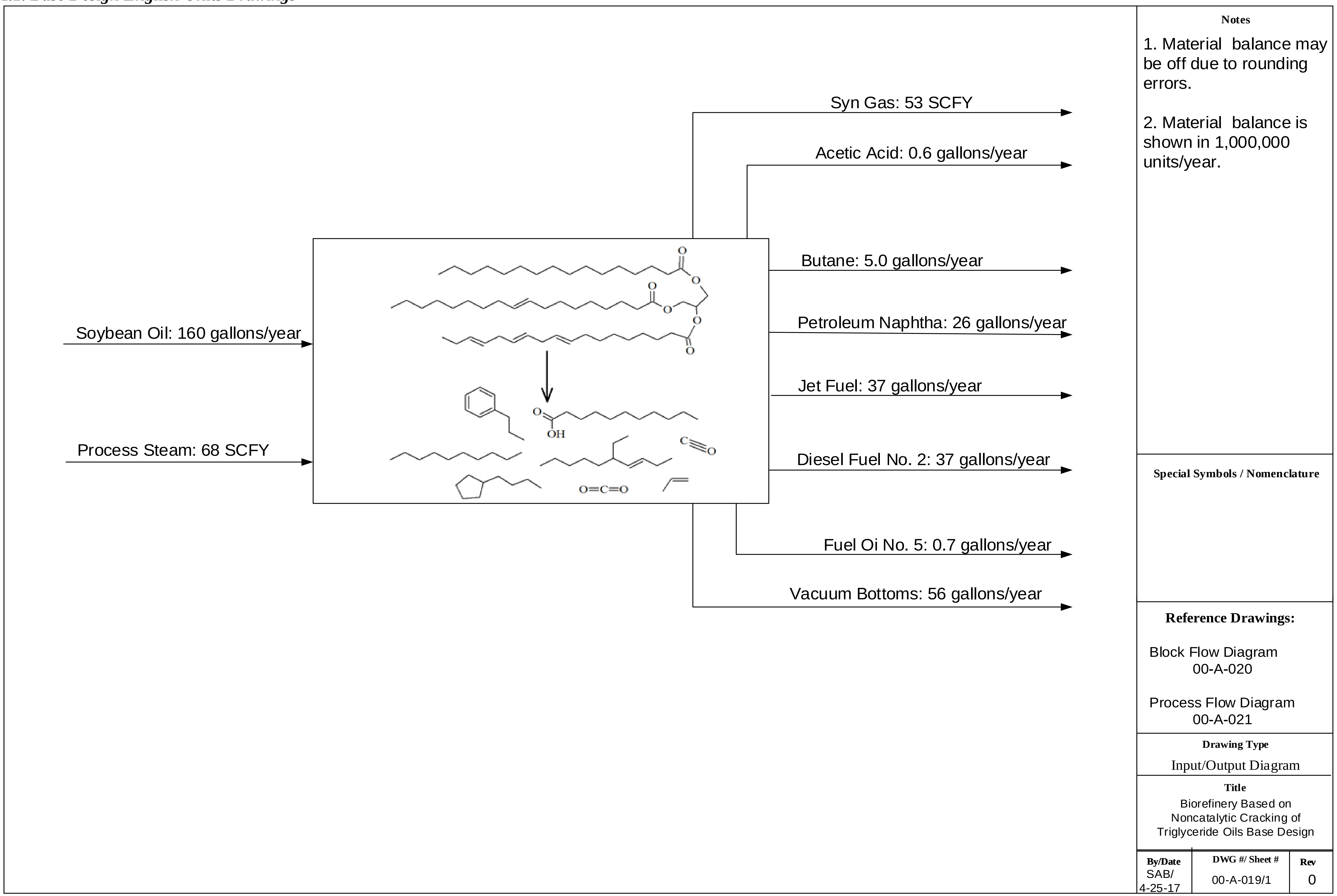
Equipment	Symbol
Single Stage Compressor	
Three Stage Compressor	
Fatty Acid Extractor	
Pitching Reactor	

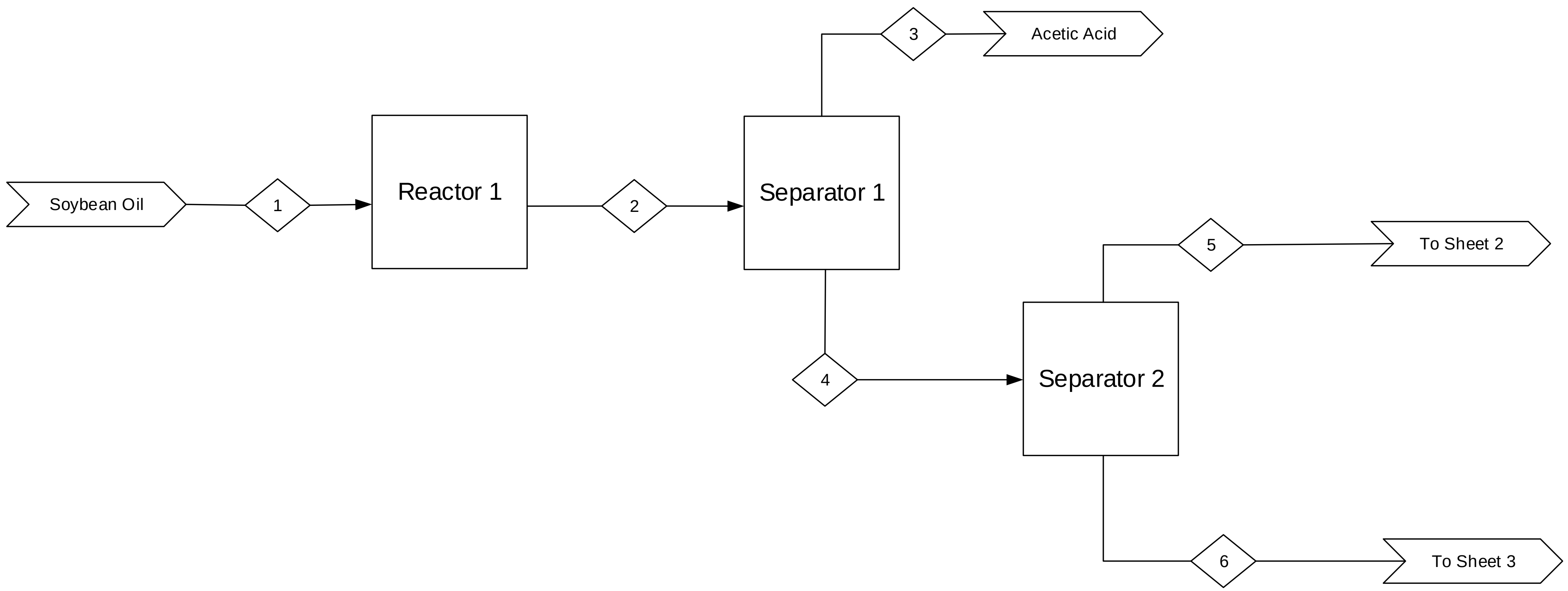
(continued)

Table I.6. Cont.

Equipment	**Symbol**
Crusher	
Screw Conveyor	
Solid Conveyor	

I.1. Base Design English Units Drawings





Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

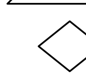
7. Reactor 1: Crack incoming TG oil into fuel intermediates

Separator 1:Separate aqueous acetic acid from organic crackate

Separator 2: Separate the naphtha range fuel intermediates from the diesel range fuel intermediates

Special Symbols / Nomenclature

Input/Output



Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-019

Process Flow Diagram
00-A-021

Drawing Type

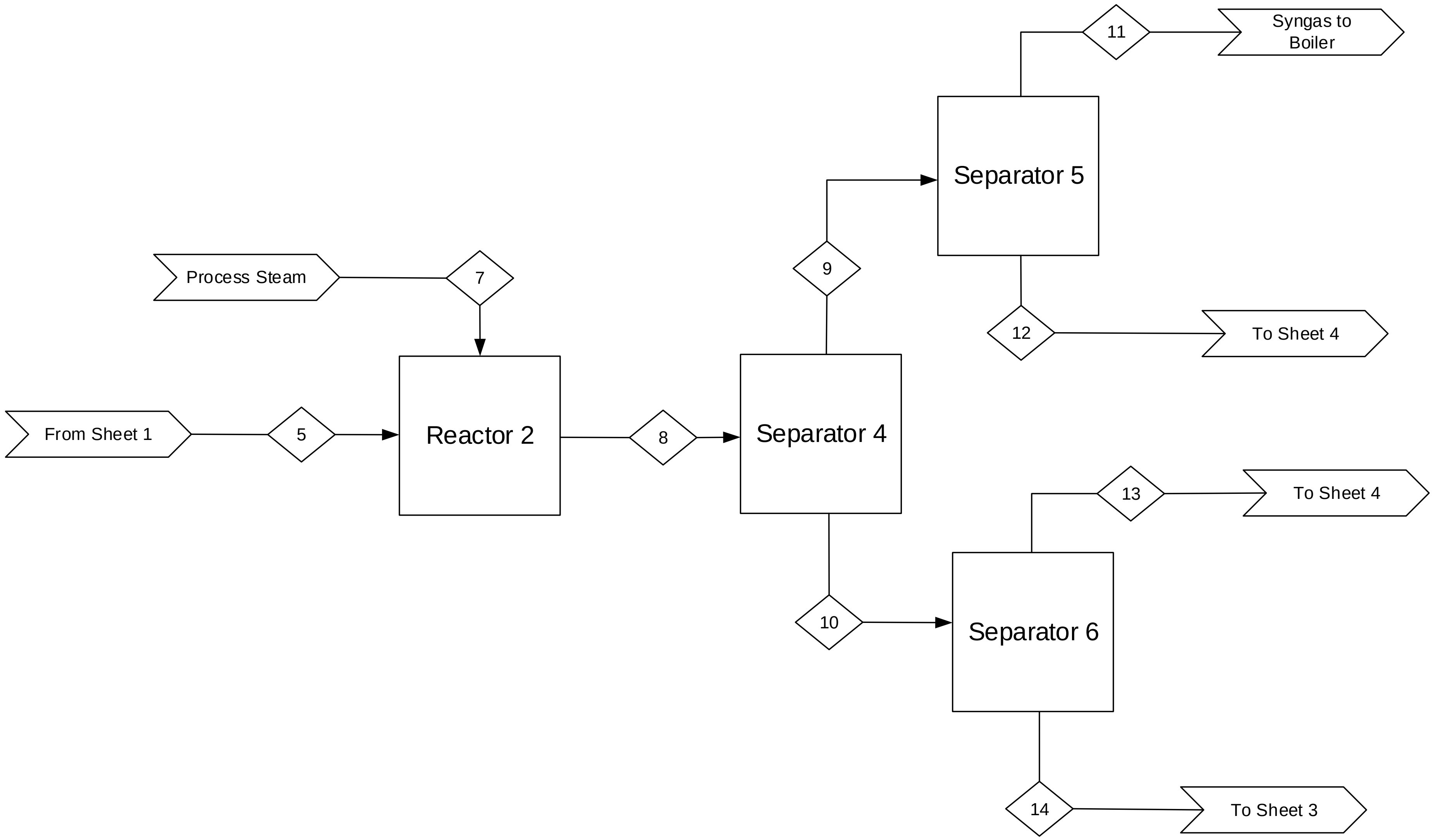
Block Flow Diagrams

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-25-17	00-A-020/1	0

Component/Stream (lb/min)	1	2	3	4	5	6
Soybean Oil	2200	0	0	0	0	0
Acetic Acid	0	0	10	0	0	0
C1-C50	0	2200	0	2200	0	0
C1-C12	0	0	0	0	950	0
C12-C50	0	0	0	0	0	1200
Total	2200	2200	10	2200	950	1200



Component/Stream (lb/min)	5	7	8	9	10	11	12	13	14
C1-C12	950	0	970	0	0	0	0	0	0
Steam	0	15	0	0	0	0	0	0	0
C1-C6	0	0	0	530	0	0	0	0	0
C1-C3	0	0	0	0	0	350	0	0	0
C4-C6	0	0	0	0	0	0	180	0	0
C7-C10	0	0	0	0	0	0	0	140	0
C11-C13	0	0	0	0	0	0	0	0	300
C7-C13	0	0	0	0	440	0	0	0	0
Total	950	15	970	530	440	350	180	140	300

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 2: Reacts the carboxylic acids and alkenes to produce hydrocarbons.

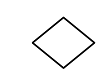
Separator 4: Removes light ends from naphtha range fuel intermediates.

Separator 5: Removes syngas from butane and naphtha intermediates.

Separator 6: Separates petroleum naphtha intermediates from jet fuel range fuel intermediates.

Special Symbols / Nomenclature


Input/Output


Stream Indicator

Reference Drawings:

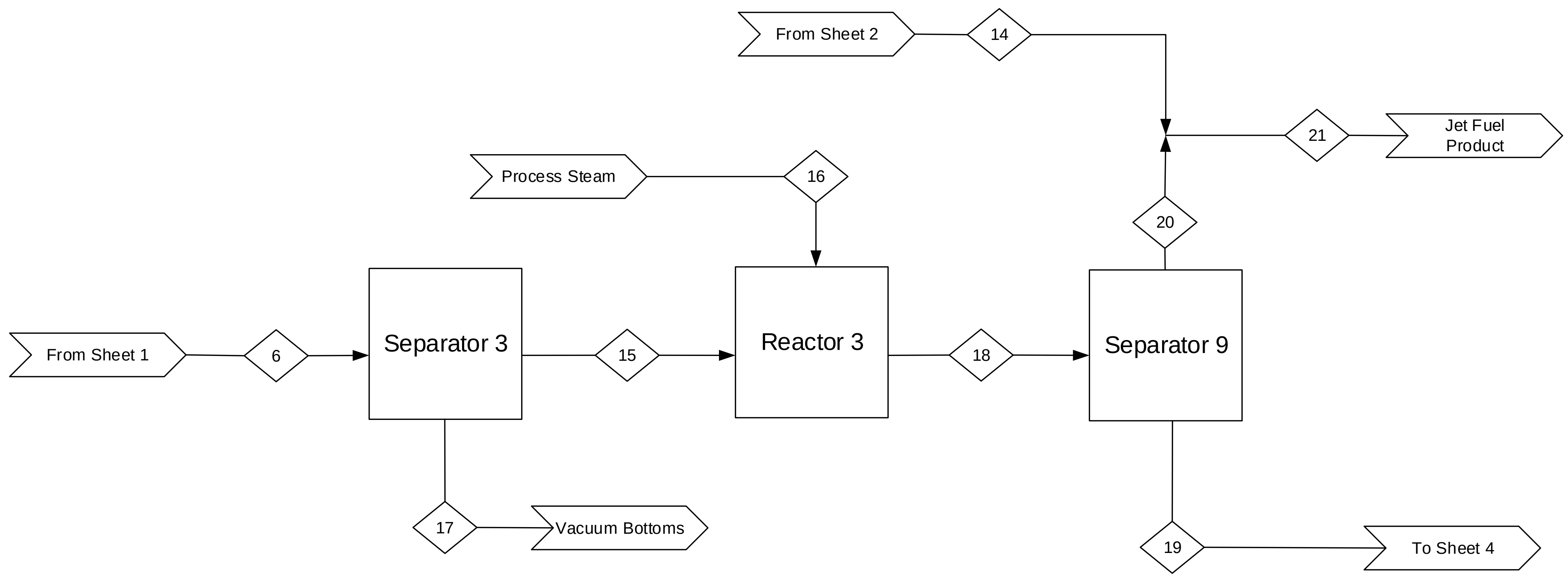
Input/Output Diagram
00-A-019

Process Flow Diagram
00-A-021

Drawing Type
Block Flow Diagram

Title
Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-25-17	00-A-020/2	0



Component/Stream (lb/min)	6	14	15	16	17	18	19	20	21
Steam	0	0	0	20	0	0	0	0	0
C12-C50	1200	0	0	0	0	0	0	0	0
C30-C50	0	0	0	0	620	0	0	0	0
C12-C30	0	0	620	0	0	640	0	0	0
C13-C15	0	0	0	0	0	0	0	160	0
C11-C13	0	300	0	0	0	0	0	0	0
C11-C15	0	0	0	0	0	0	0	0	470
C15-C30	0	0	0	0	0	0	480	0	0
Total	1200	300	620	20	620	640	480	160	470

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 3: Reacts carboxylic acids and alkenes to produce hydrocarbons.

Separator 3: Separates diesel fuel range intermediates from the vacuum bottoms.

Separator 9: Separates jet fuel range fuel intermediates from diesel fuel range intermediates.

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram 00-A-019

Process Flow Diagram 00-A-021

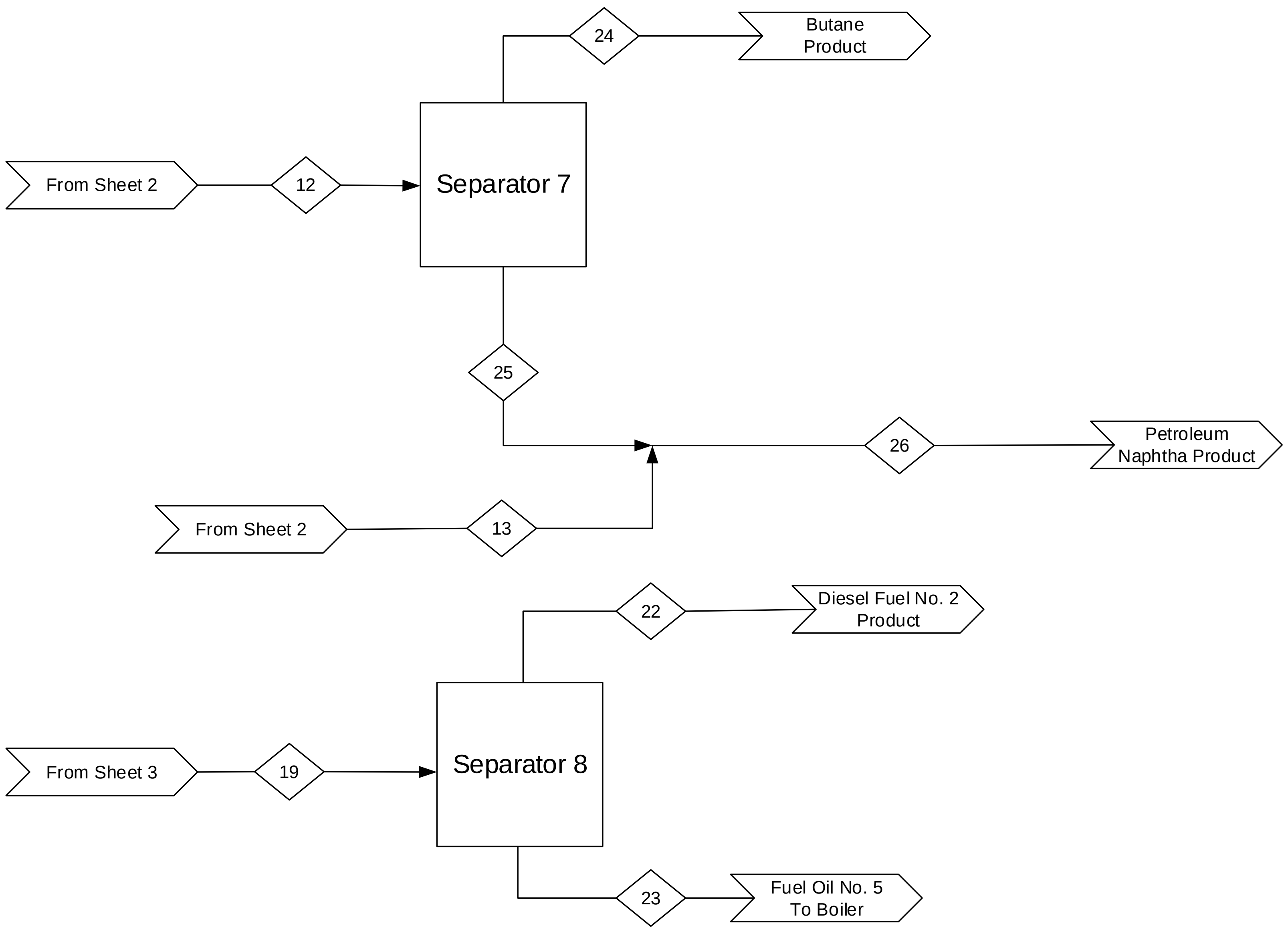
Drawing Type

Block Flow Diagram

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-25-17	00-A-020/3	0



Component/Stream (lb/min)	12	13	19	22	23	24	25	26
C4-C6	180	0	0	0	0	0	0	0
C4	0	0	0	0	0	45	0	0
C5-C6	0	0	0	0	0	0	140	0
C7-C10	0	140	0	0	0	0	0	0
C5-C10	0	0	0	0	0	0	0	280
C15-C22	0	0	0	470	0	0	0	0
C23-C30	0	0	0	0	9	0	0	0
C15-C30	0	0	480	0	0	0	0	0
Total	180	140	480	470	9	45	140	280

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Separator 7: Separates butane byproduct from naphtha range intermediates.

Separator 8: Separates the diesel fuel no. 2 product from the fuel oi no 5. product.

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-019

Process Flow Diagram
00-A-021

Drawing Type

Block Flow Diagram

Title

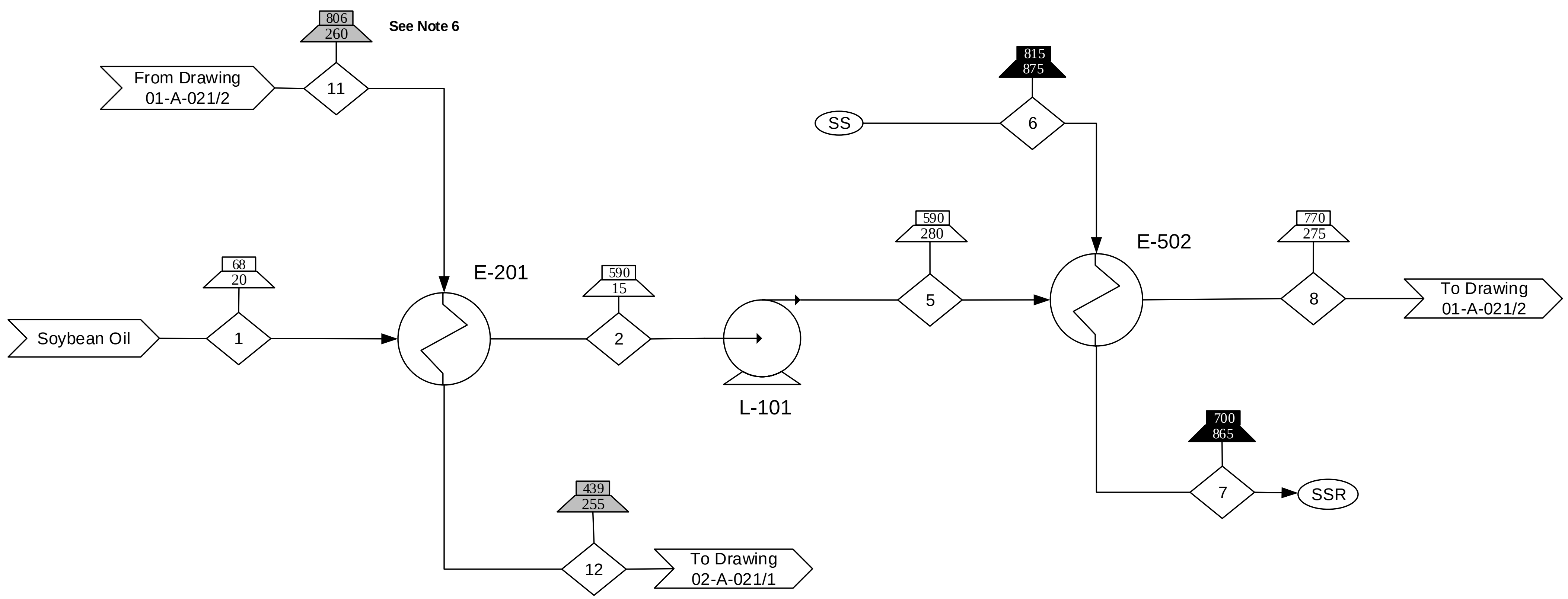
Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-25-17	00-A-020/4	0

E-201 A/B
Post Cracking Cooler
Area = 3400 ft^2
Duty = 4.9 x 10^7 Btu/hr

E-502 A/B
TTCR Preheat
Area = 4900 ft^2
Duty = 2.2 x 10^7 Btu/hr

L-101 A/B
PreCracking Pump
Power = 96 hp



Component/Stream (lb/min)	1	2	5	6	7	8	11	12
Soybean Oil	2200	2200	2200	0	0	2200	0	0
C1-C50	0	0	0	0	0	0	2200	2200
Water	0	0	0	5300	5300	0	0	0
Total	2200	2200	2200	5300	5300	2200	2200	2200

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 11 and 12 is an organic, aqueous, gaseous three phase stream.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas
- Temperature (°F) Indicator, Two Phase
- Pressure (psia) Indicator, Two Phase
- SS Superheated Steam
- SSR Superheated Steam Recycle

Reference Drawings:

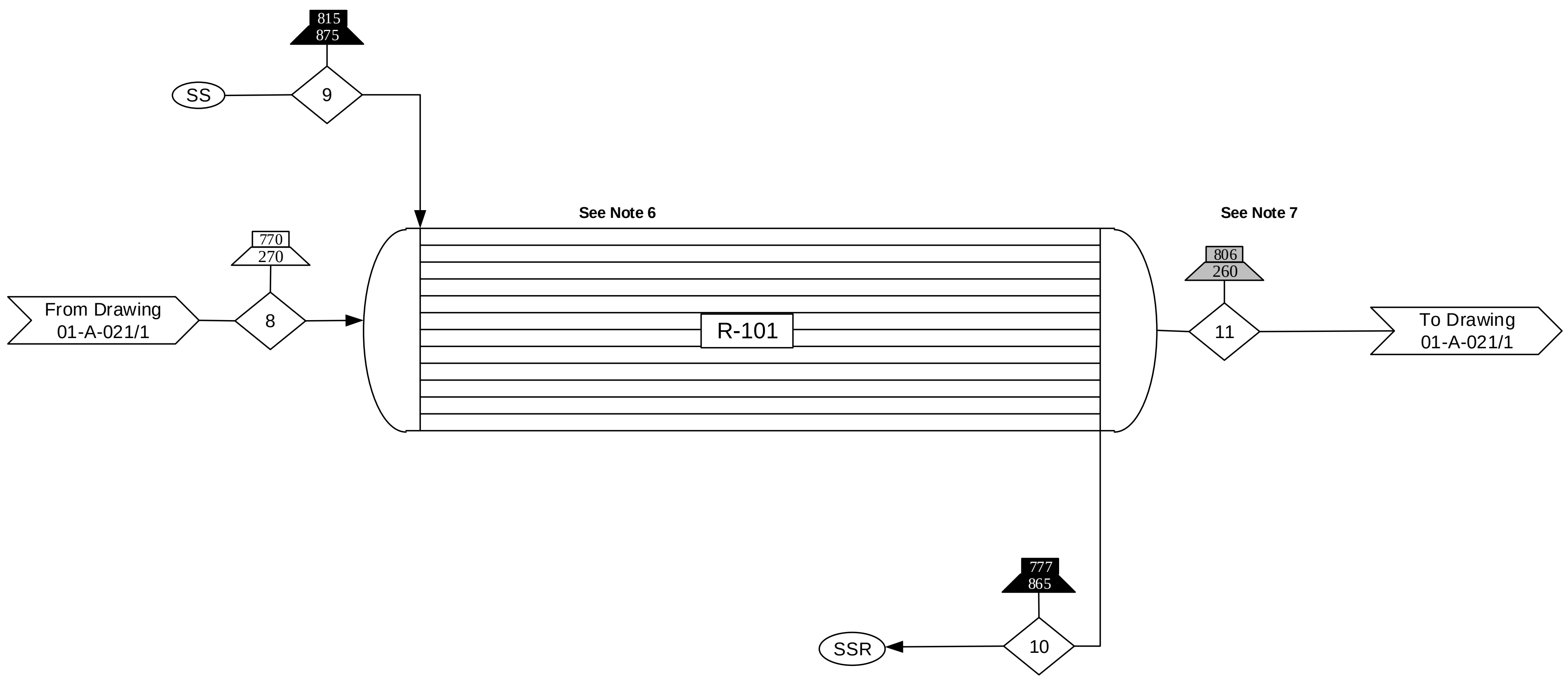
Input/Output Diagram
00-A-019
Block Flow Diagrams
00-A-020
Process Flow Diagrams
01-A-021

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design-
Thermal Cracking Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	01-A-021/1	0

R-101
TTCR
Diameter= 20 ft
Length= 40 ft
Tubes= 10300



Component/Stream (lb/min)	8	9	10	11
Soybean Oil	2200	0	0	0
C1-C50	0	0	0	2200
Water	0	18000	18000	0
Total	2200	18000	18000	2200

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. R-101 has a residence time of 1.17 hr.
7. Stream 11 is composed of a gas phase stream with entrained liquid tars.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
SS Superheated Steam
SR Superheated Steam Recycle

Reference Drawings:

Input/Output Diagrams
00-A-019
Block Flow Diagrams
00-A-020
Process Flow Diagrams
01-A-021
02-A-021

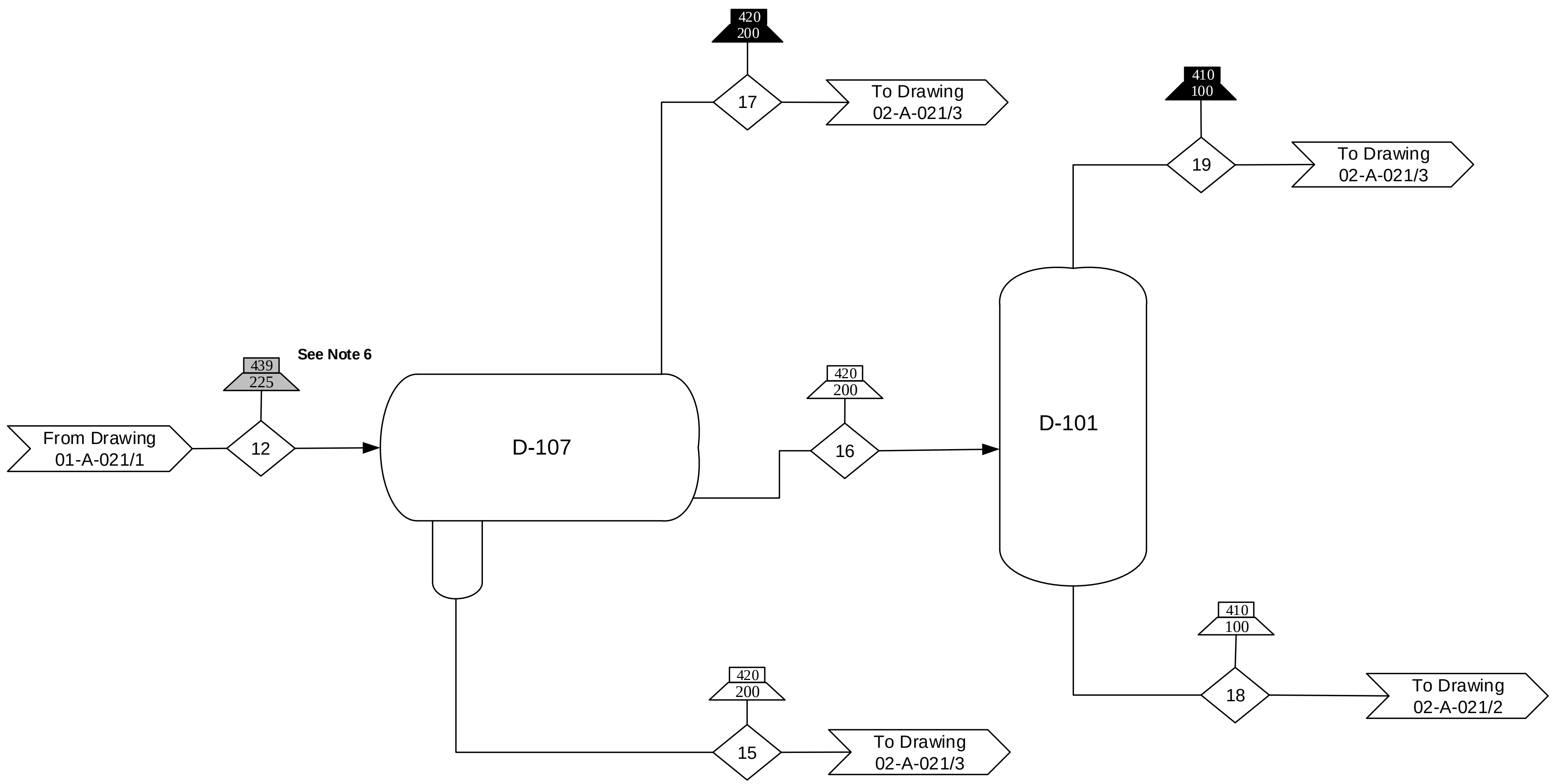
Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design - Thermal Cracking Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	01-A-021/2	0

D-101
Flash 1
Height= 19 ft
Diameter= 4.5 ft

D-107
Acetic Flash 1
Length= 6 ft
Diameter= 1.5 ft



Component/Stream (lb/min)	12	15	16	17	18	19
C1-C50	2200	0	0	0	0	0
C1-C8	0	0	0	460	0	20
C7-C50	0	0	1700	0	1700	0
Acetic Acid	0	6	0	0	0	0
Propionic Acid	0	1	0	0	0	0
Total	2200	7	1700	460	1700	20

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 12 is composed of an aqueous and organic three phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase

Reference Drawings:

Input/Output Diagram
00-A-019
Block Flow Diagram
00-A-020
Process Flow Diagrams
01-A-021
02-A-021

Drawing Type
Process Flow Diagram

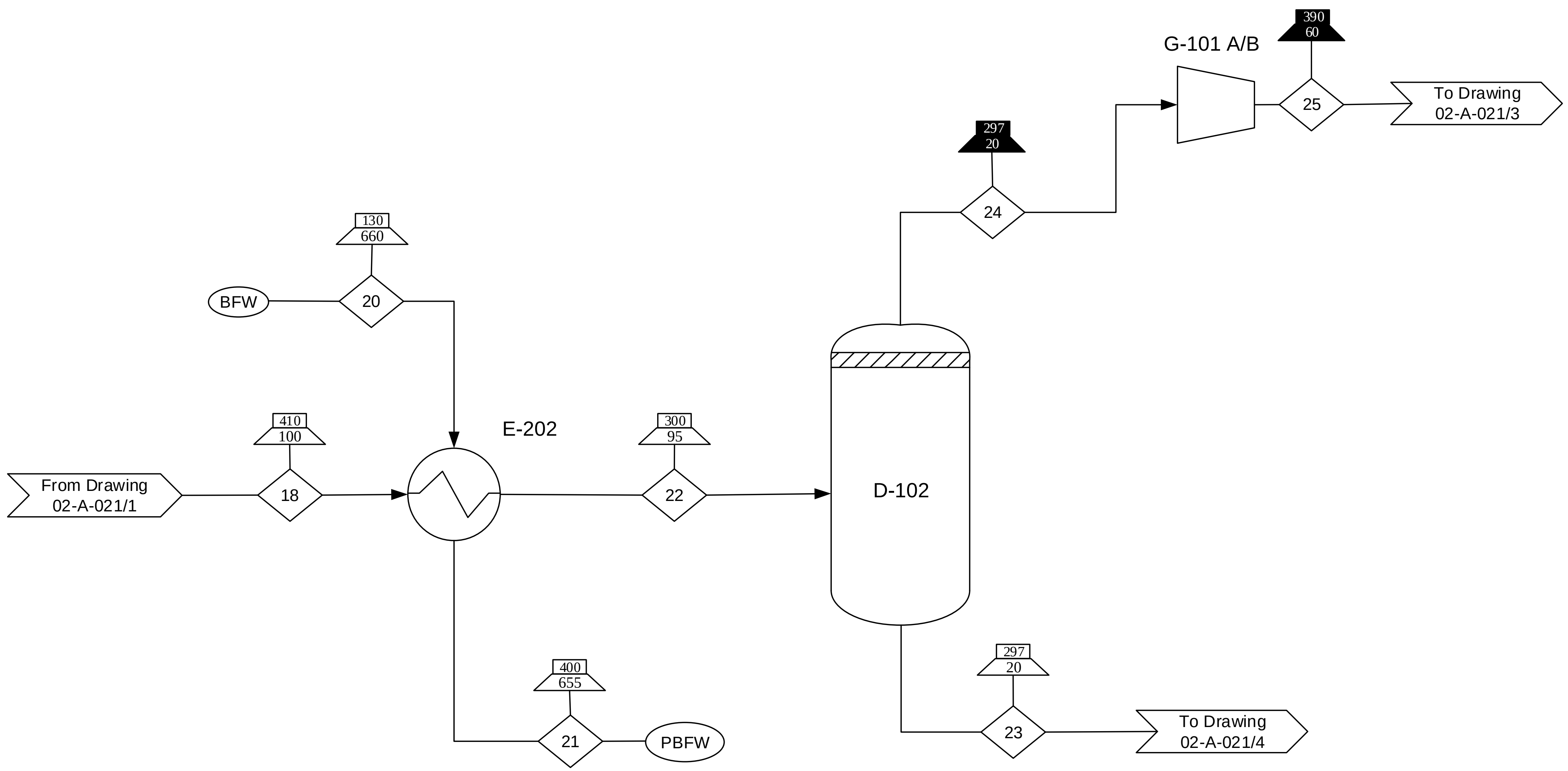
Title
Biorefinery Base Design-
Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	02-A-021/1	0

D-102
Flash 2
Height= 17.5 ft
Diameter= 4.5 ft

E-202 A/B
Flash 2 Cooler
Area= 1900 ft^2
Duty= 9.3×10^6 Btu/hr

G-101 A/B
Flash 2 Compressor
Power= 22 hp



Component/Stream (lb/min)	18	20	21	22	23	24	25
C1-C8	0	0	0	0	0	20	20
C7-C50	1700	0	0	1700	1700	0	0
Water	0	190	190	0	0	0	0
Total	1700	190	190	1700	1700	20	20

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

◇	Stream Indicator
⟩	Input/Output
▭	Temperature (°F) Indicator, Liquid/Solid
⏢	Pressure (psia) Indicator, Liquid/Solid
▬	Temperature (°F) Indicator, Gas
▲	Pressure (psia) Indicator, Gas
BFW	Boiler Feed Water
PBFW	Preheated Boiler Feed Water

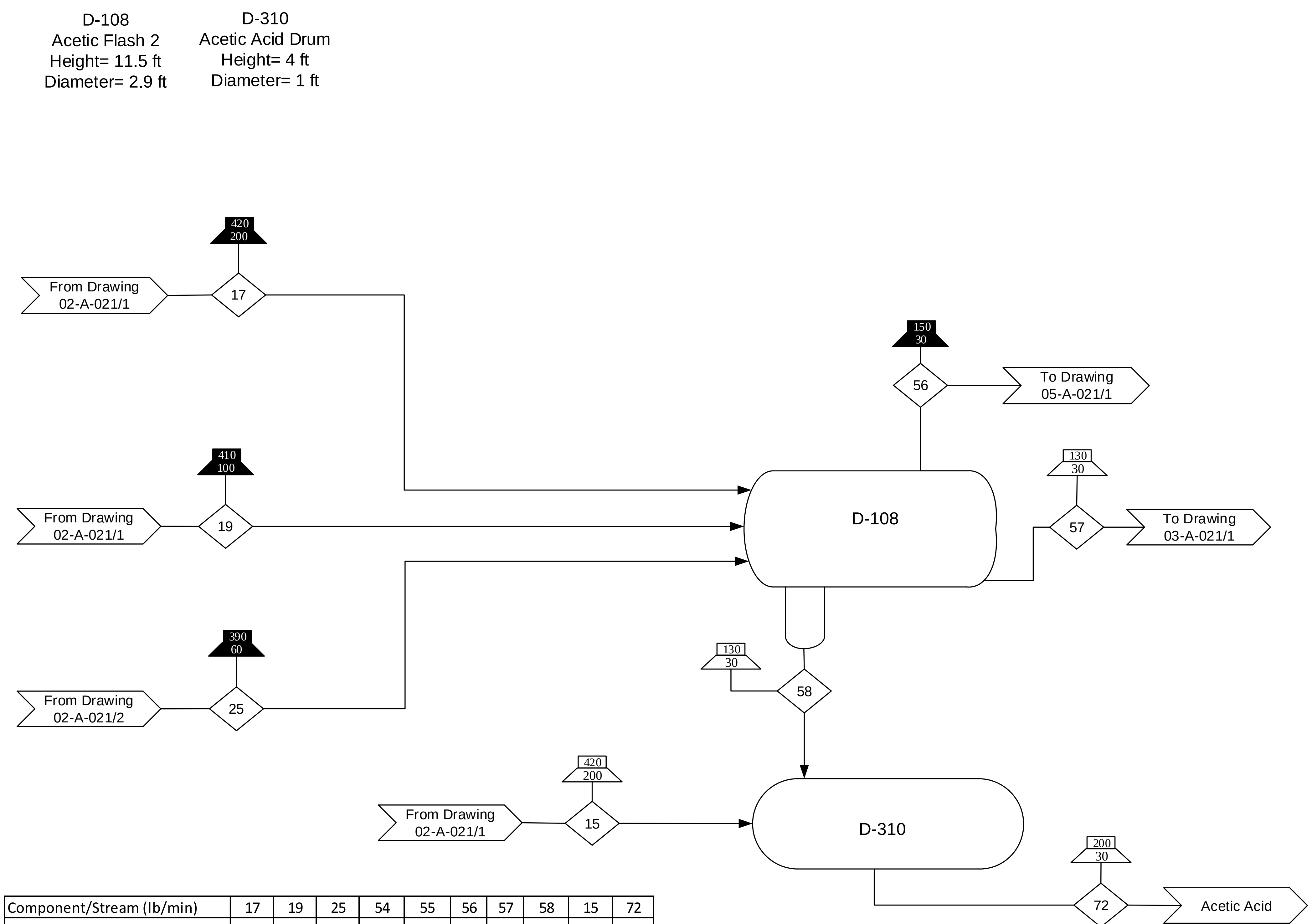
Reference Drawings:

Input/Output Diagrams
00-A-019
Block Flow Diagrams
00-A-020
Process Flow Diagrams
02-A-021

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design-Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	02-A-021/2	0



Component/Stream (lb/min)	17	19	25	54	55	56	57	58	15	72
C1-C8	460	20	20	0	0	0	0	0	0	0
C1-C6	0	0	0	0	0	380	0	0	0	0
C6-C8	0	0	0	0	0	0	120	0	0	0
Water	0	0	0	4100	4100	0	0	0	0	0
Acetic Acid	0	Trace	Trace	0	0	Trace	0	3	6	9
Propionic Acid	0	Trace	Trace	0	0	0	0	Trace	1	1
Total	460	20	20	4100	4100	380	120	3	7	10

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°F) Indicator, Liquid/Solid

Pressure (psia) Indicator, Liquid/Solid

Temperature (°F) Indicator, Gas

Pressure (psia) Indicator, Gas

Reference Drawings:

Input/Output Diagram
00-A-019
Block Flow Diagram
00-A-020
Process Flow Diagrams
02-A-021
03-A-021
05-A-021

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design-Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	02-A-021/3	0

D-201
Atmospheric Column
Height= 28 ft
Diameter= 8 ft
Trays= 7
Feed= Tray 3

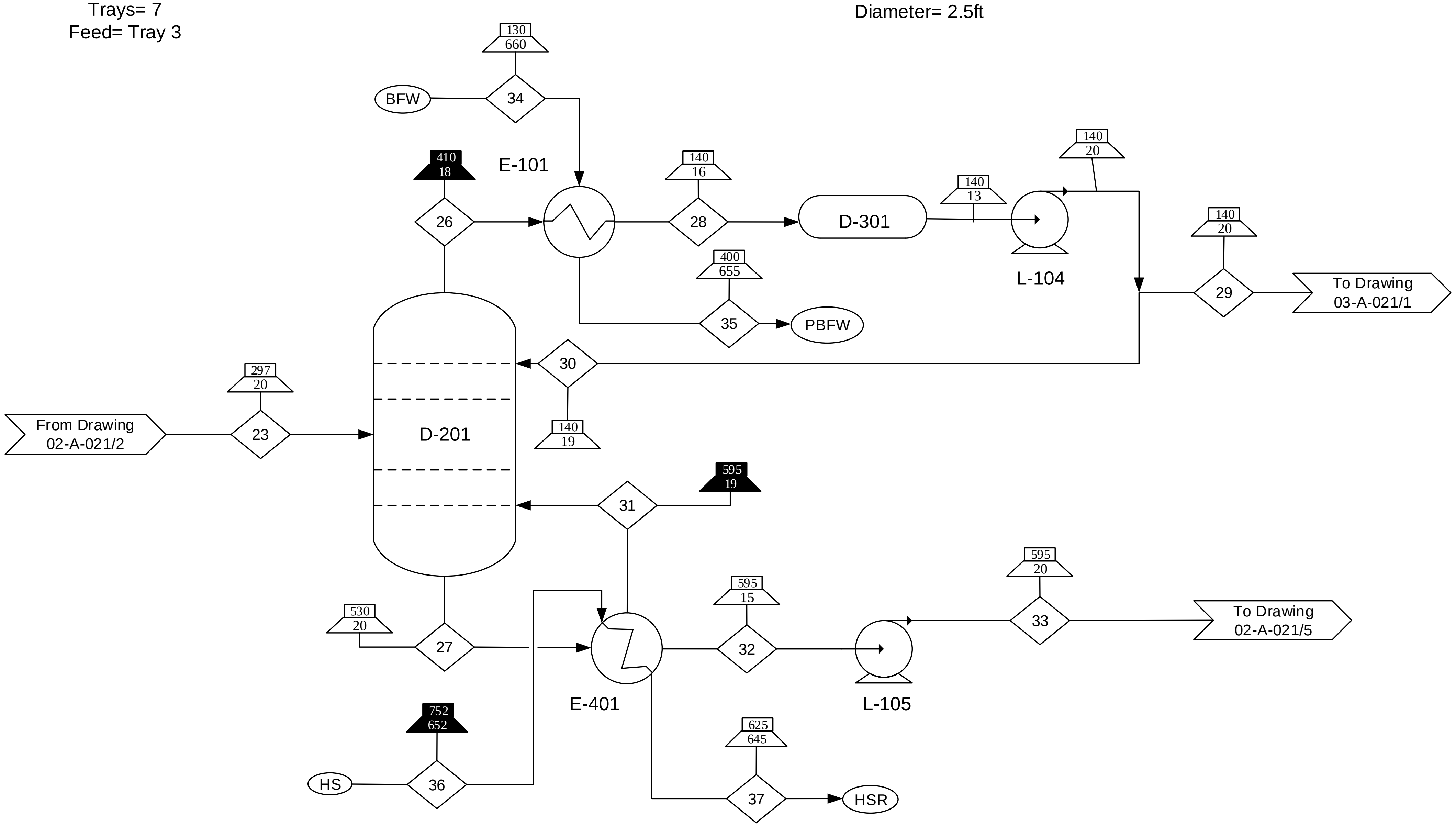
E-101 A/B
Atmospheric Column Condenser
Area= 7100 ft^2
Duty= 8.5×10^6 Btu/hr

E-401 A/B
Atmospheric Column Reboiler
Area= 2200 ft^2
Duty= 2.5×10^7 Btu/hr

D-301
Atmospheric Column Reflux Drum
Length= 10ft
Diameter= 2.5ft

L-104 A/B
Atmospheric Reflux
Power= 2 hp

L-105 A/B
Atmospheric Bottoms
Power= 1 hp

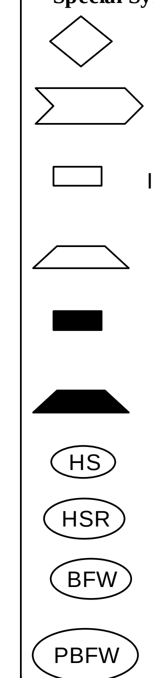


Component/Stream (lb/min)	23	26	27	28	29	30	31	32	33	34	35	36	37
C7-C12	0	400	0	400	370	30	0	0	0	0	0	0	0
C7-C50	1700	0	3200	0	0	0	1900	0	0	0	0	0	0
C13-C50	0	0	0	0	0	0	0	1300	1300	0	0	0	0
Water	0	0	0	0	0	0	0	0	0	170	170	5600	5600
Total	1700	400	3200	400	370	30	1900	1300	1300	170	170	5600	5600

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



Reference Drawings:

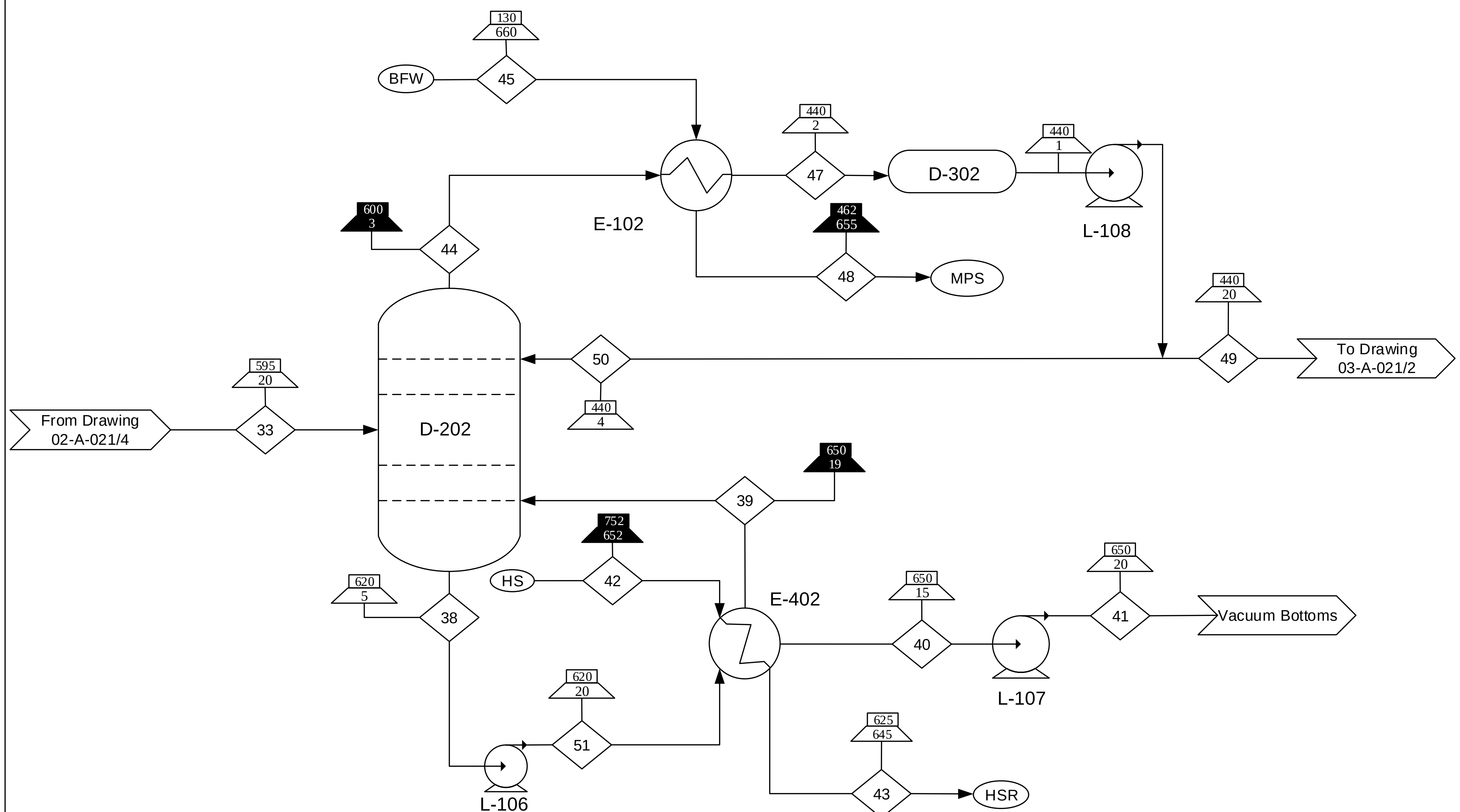
Input/Output Diagram
00-A-019
Block Flow Diagram
00-A-020
Process Flow Diagrams
02-A-021
03-A-021

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	02-A-021/4	0

D-202	E-102 A/B	E-402 A/B	D-302	L-106 A/B	L-107 A/B	L-108 A/B
Vacuum Column	Vacuum Column Condenser	Vacuum Column Reboiler	Vacuum Column Reflux Drum	Vacuum Column Bottoms	Vacuum Bottoms	Vacuum Reflux
Height= 67 ft	Area= 600 ft^2	Area= 9030 ft^2	Length= 18 ft	Power= 6 hp	Power= 1 hp	Power= 7 hp
Diameter= 9.5 ft	Duty= 1.9x10^7 Btu/hr	Duty= 1.5x10^7 Btu/hr	Diameter= 4.5 ft			
Trays= 20						
Feed= Tray 5						



Component/Stream (lb/min)	33	38	39	40	41	42	43	44	45	46	47	48	49	50	51
C12-C50	1300	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C12-C30	0	0	0	0	0	0	0	1700	0	1700	1700	0	700	950	0
C30-C50	0	2200	1600	2200	620	0	0	0	0	0	0	0	0	0	2200
Water	0	0	0	0	0	3300	3300	0	380	0	0	380	0	0	0
Total	1300	2200	1600	2200	620	3300	3300	1700	380	1700	1700	380	700	950	2200

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
HS High Pressure Steam
HSR High Pressure Steam Recycle
BFW Boiler Feed Water
MPS Medium Pressure Steam

Reference Drawings:

Input/Output Diagrams
00-A-019
Block Flow Diagrams
00-A-020
Process Flow Diagrams
02-A-021
03-A-021

Drawing Type
Process Flow Diagram

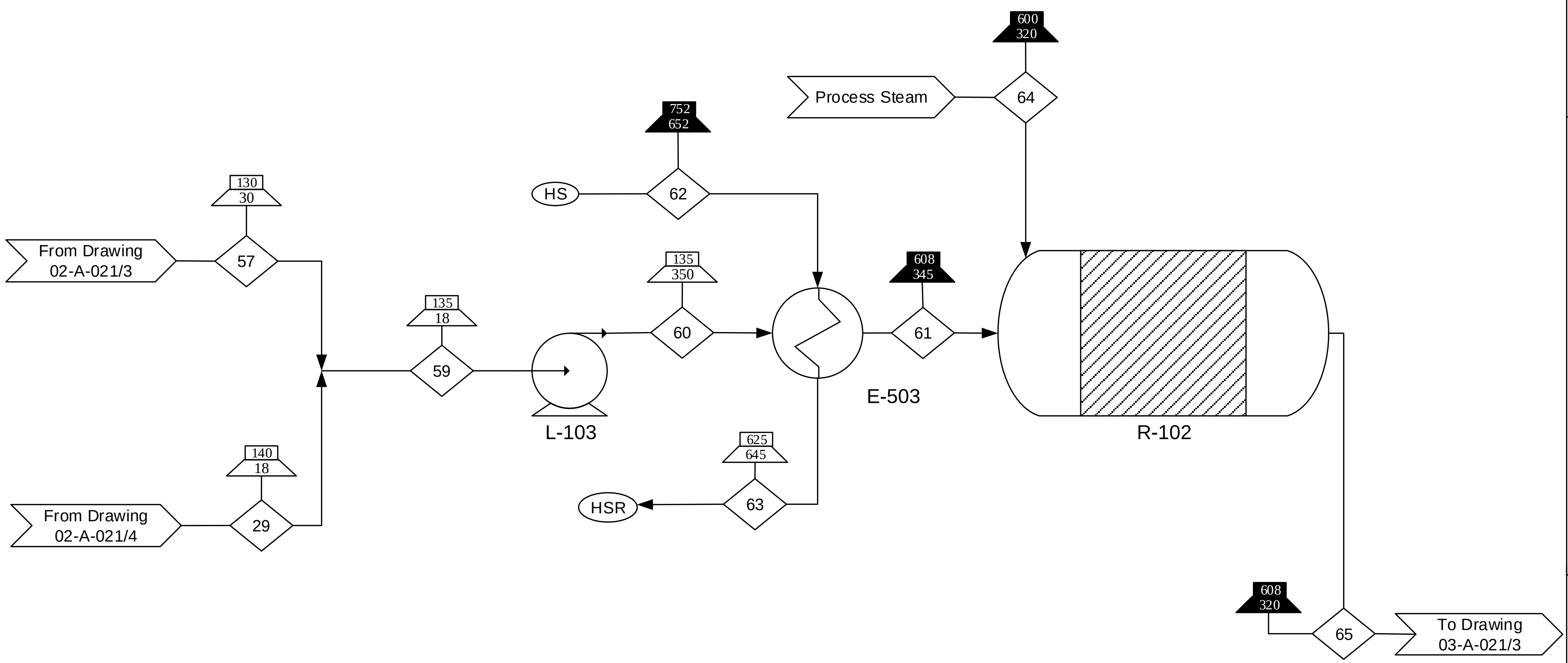
Title
Biorefinery Base Design-Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	02-A-021/5	0

R-102 A/B
Naphtha Decarboxylation Reactor
Diameter= 9 ft
Length= 56 ft
Catalyst= 7700 ft^3

E-503 A/B
Naphtha Decarbox Heater
Area= 460 ft^2
Duty= $1.3x10^7$ Btu/hr

L-103 A/B
PreNaphtha Decarbox Pump
Power= 23 hp



Component/Stream (lb/min)	29	57	59	60	61	62	63	64	65
C6-C8	0	120	0	0	0	0	0	0	0
C7-C12	370	0	0	0	0	0	0	0	0
C6-C12	0	0	490	490	490	0	0	0	0
C1-C12	0	0	0	0	0	0	0	0	510
Water	0	0	0	0	0	2800	2800	15	0
Total	370	120	490	490	490	2800	2800	15	510

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
HS High Pressure Steam
HSR High Pressure Steam Recycle

Reference Drawings:

Input/Output Diagram
00-A-019
Block Flow Diagram
00-A-020
Process Flow Diagrams
02-A-021
03-A-021

Drawing Type
Process Flow Diagram

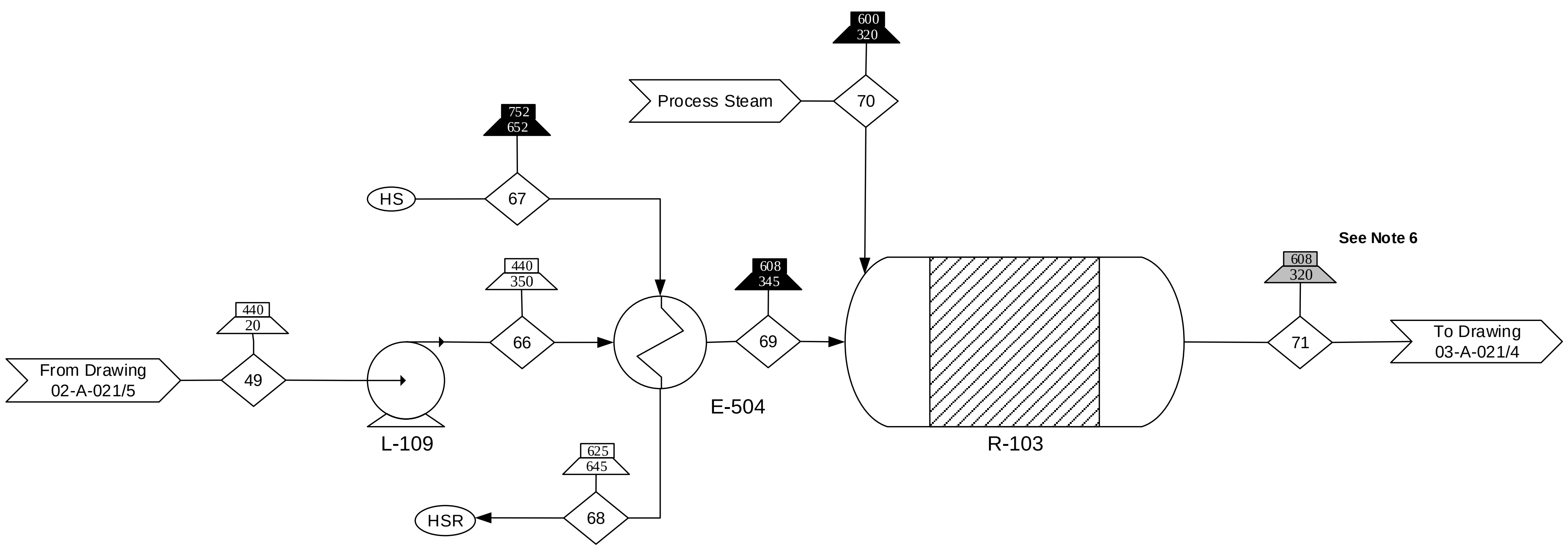
Title
Biorefinery Base Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	03-A-021/1	0

R-103 A/B
Diesel Decarboxylation Reactor
Diameter= 11 ft
Length= 63 ft
Catalyst= 11000 ft^3

E-504 A/B
Diesel Decarbox Heater
Area= 440 ft^2
Duty= 6.1×10^6 Btu/hr

L-109 A/B
Pre Diesel Decarbox Pump
Power= 39 hp



Component/Stream (lb/min)	49	66	67	68	69	70	71
C12-C30	700	700	0	0	700	0	0
C1-C30	0	0	0	0	0	0	720
Water	0	0	1400	1400	0	21	0
Total	700	700	1400	1400	700	21	720

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 71 is composed of a liquid gas two phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
HS High Pressure Steam
HSR High Pressure Steam Recycle

Reference Drawings:

Input/Output Diagram
00-A-019
Block Flow Diagram
00-A-020
Process Flow Diagrams
02-A-021
03-A-021

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	03-A-021/2	0

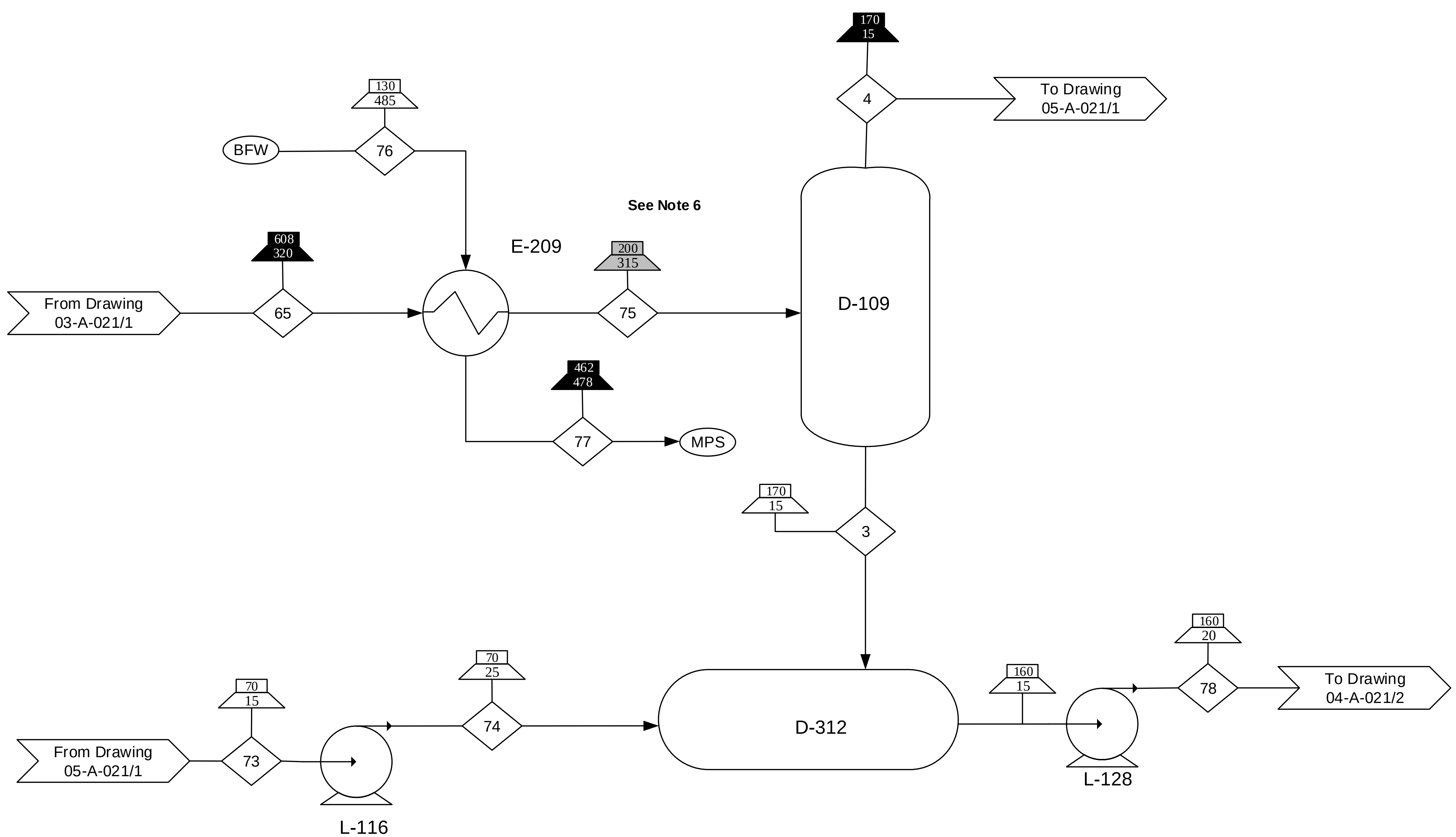
D-109
Flash 7
Height= 9 ft
Diameter= 2.5 ft

E-209 A/B
Post Naphtha Decarbox Cooler
Area = 800 ft^2
Duty = 1.2 x 10^7 Btu/hr

D-312
Flash 7 Drum
Height = 14 ft
Diameter = 3.5 ft

L-116 A/B
Flash 5 Pump
Power = 1 hp

L-128 A/B
Flash 7 Pump
Power = 1 hp



Component/Stream (lb/min)	65	73	74	75	76	77	3	4	78
C1-C12	510	0	0	510	0	0	0	0	0
C6-C9	0	50	50	0	0	0	0	0	440
C1-C4	0	0	0	0	0	0	0	120	0
C4-C12	0	0	0	0	0	0	390	0	0
Water	0	0	0	0	200	200	0	0	0
Total	510	50	50	510	200	200	390	120	440

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 75 is composed of a liquid and gas two phase stream.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas
- Temperature (°F) Indicator, Two Phase
- Pressure (psia) Indicator, Two Phase
- MPS Medium Pressure Steam
- BFW Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-019
Block Flow Diagram
00-A-020
Process Flow Diagrams
03-A-021
04-A-021
05-A-021

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design – Decarboxylation Section

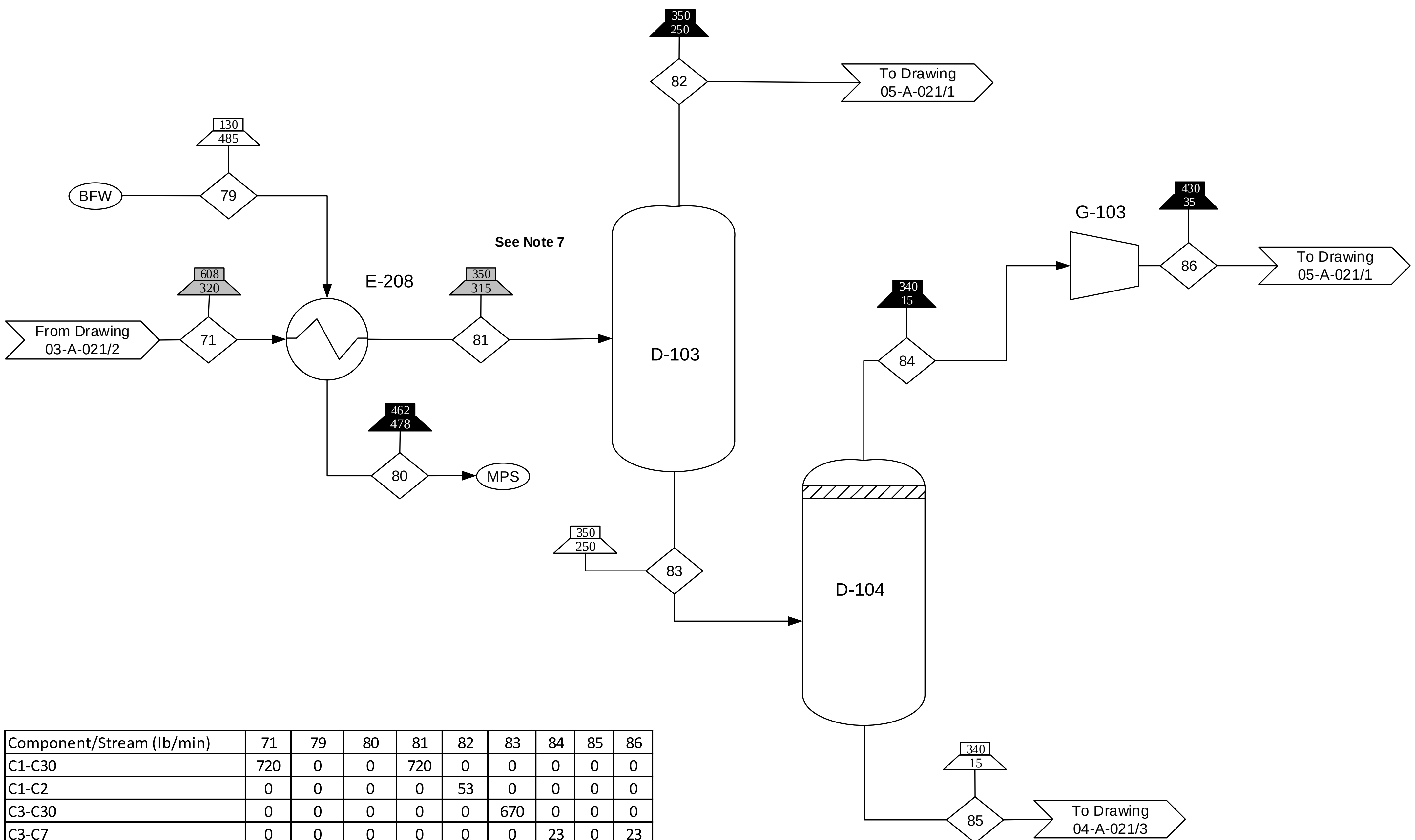
By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	03-A-021/3	0

D-103
Flash 3
Height= 16 ft
Diameter= 4 ft

D-104
Flash 4
Height= 15.5 ft
Diameter= 4 ft

E-208 A/B
Post Diesel Decarbox Cooler
Area= 350 ft^2
Duty= 9.6×10^6 Btu/hr

G-103 A/B
Flash 5 Compressor
Power= 20 hp



Component/Stream (lb/min)	71	79	80	81	82	83	84	85	86
C1-C30	720	0	0	720	0	0	0	0	0
C1-C2	0	0	0	0	53	0	0	0	0
C3-C30	0	0	0	0	0	670	0	0	0
C3-C7	0	0	0	0	0	0	23	0	23
C8-C30	0	0	0	0	0	0	0	640	0
Water	0	150	150	0	0	0	0	0	0
Total	720	150	150	720	53	670	23	640	23

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
7. Streams 71 and 81 are composed of a liquid and gas two phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
MPS Medium Pressure Steam
BFW Boiler Feed Water

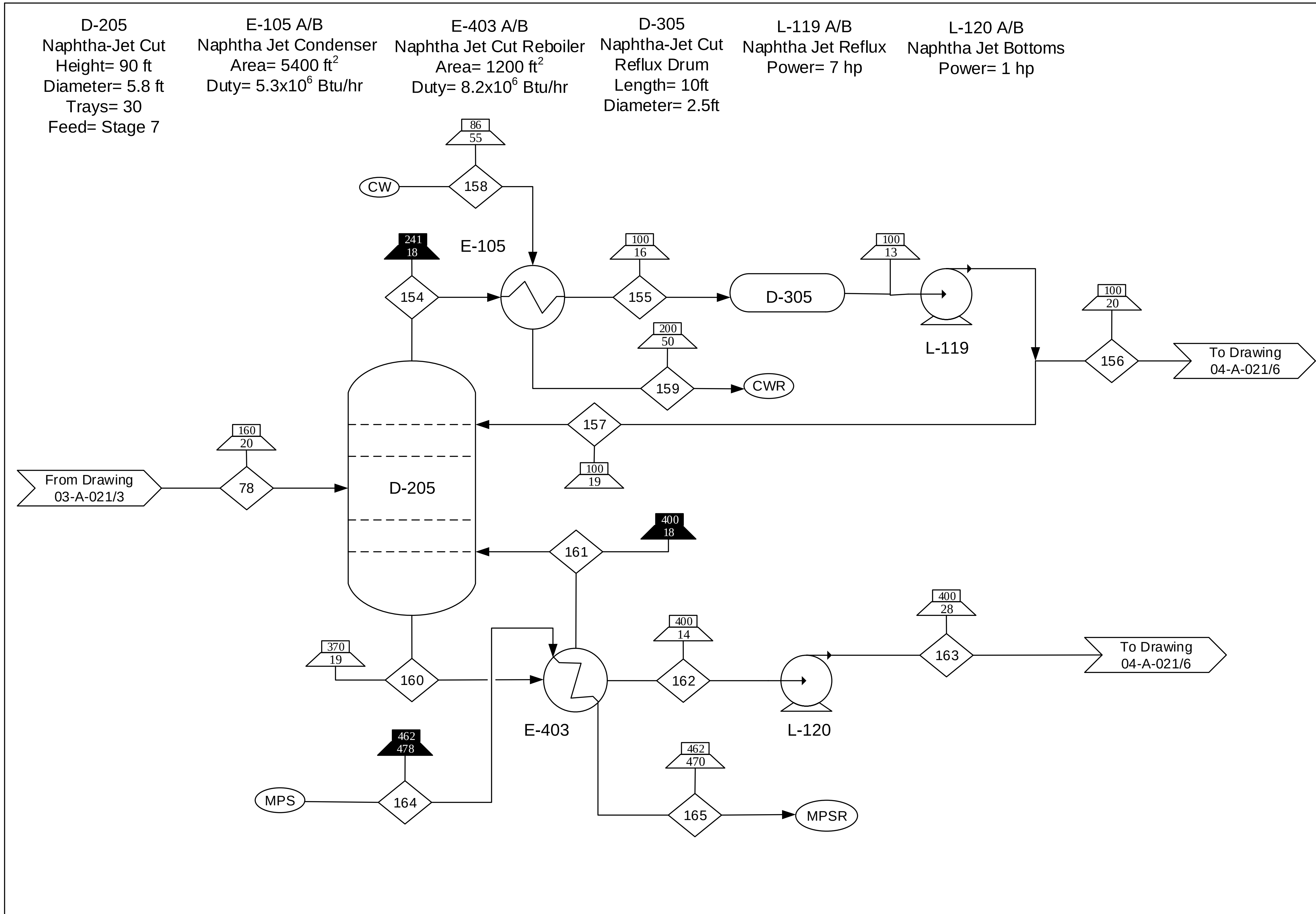
Reference Drawings:

Process Flow Diagrams
03-A-021
04-A-021
05-A-021

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design–Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	03-A-021/4	0



Component/Stream (lb/min)	78	154	155	156	157	158	159	160	161	162	163	164	165
C7-C12	440	0	0	0	0	0	0	0	0	0	0	0	0
C7-C9	0	320	320	140	180	0	0	0	0	0	0	0	0
C9-C12	0	0	0	0	0	0	0	720	420	300	300	0	0
Water	0	0	0	0	0	320	320	0	0	0	0	180	180
Total	440	320	320	140	180	320	320	720	420	300	300	180	180

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in lb/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
MPS — Medium Pressure Steam
MPSR — Medium Pressure Steam Recycle
CW — Cooling Water
CWR — Cooling Water Recycle

Reference Drawings:

Input/Output Diagram
00-A-019
Block Flow Diagram
00-A-020
Process Flow Diagrams
03-A-021
04-A-021

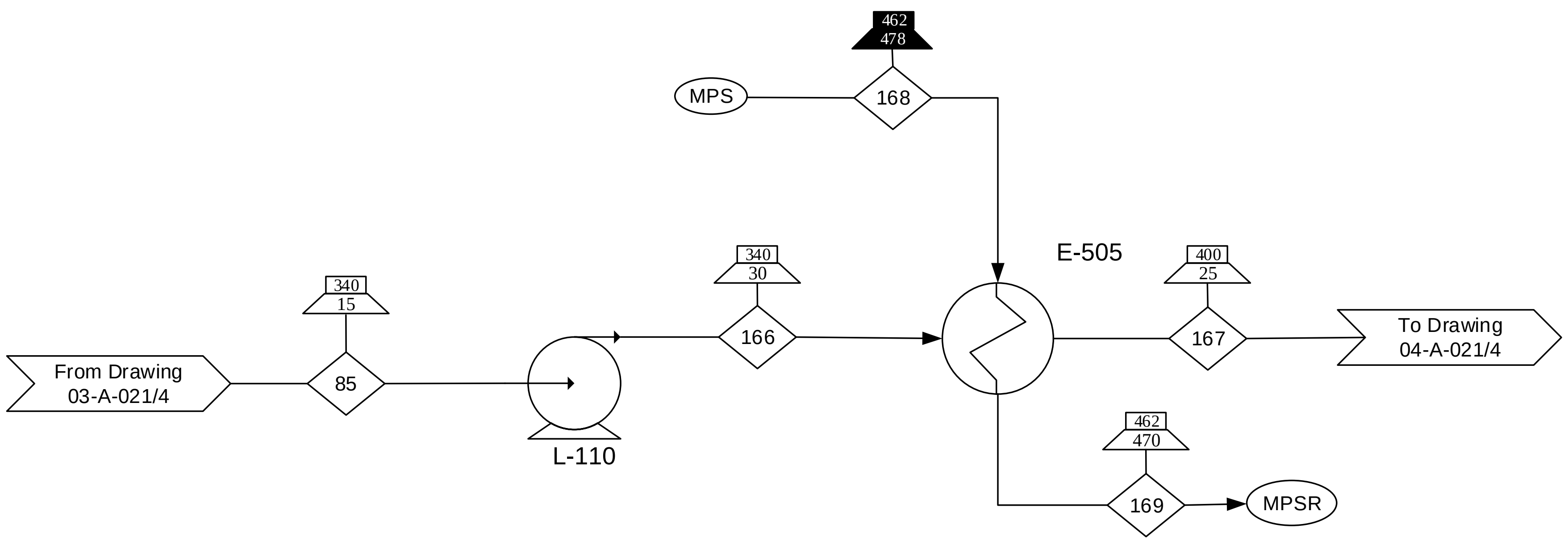
Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	04-A-021/2	0

E-505 A/B
Pre Jet Diesel Cut Heat
Area = 240 ft^2
Duty = 1.8 x 10^6 Btu/hr

L-110 A/B
Pre Jet Diesel Cut Heat Pump
Power = 2 hp

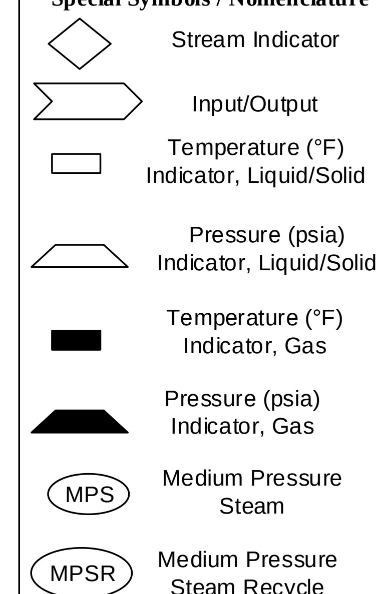


Component/Stream (lb/min)	85	166	167	168	169
C8-C30	640	640	640	0	0
Water	0	0	0	40	40
Total	640	640	640	40	40

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams

Special Symbols / Nomenclature



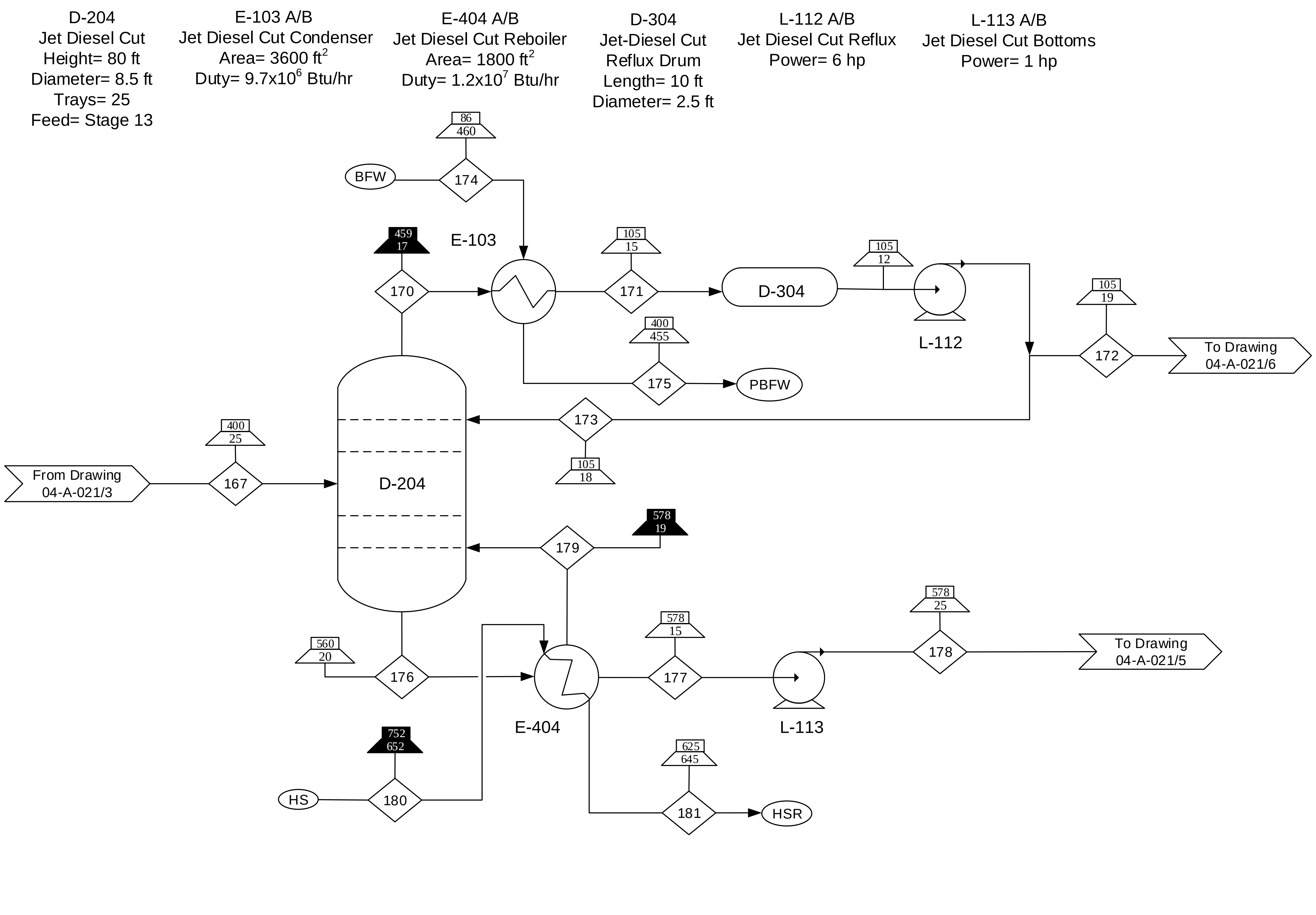
Reference Drawings:

Input/Output Diagram
00-A-019
Block Flow Diagram
00-A-020
Process Flow Diagrams
03-A-021
04-A-021

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design– Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	04-A-021/3	0

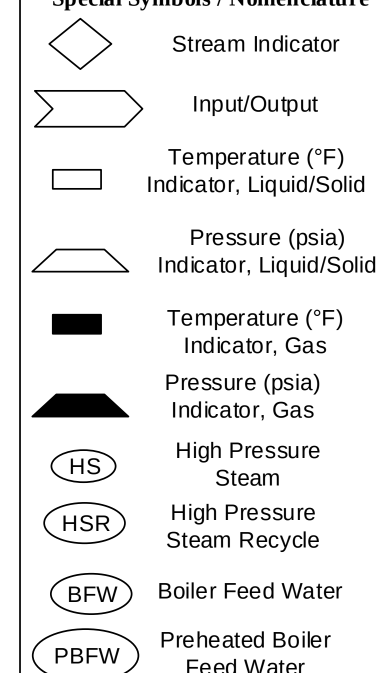


Component/Stream (lb/min)	167	170	171	172	173	174	175	176	177	178	179	180	181
C8-C30	640	0	0	0	0	0	0	0	0	0	0	0	0
C8-C15	0	410	410	160	250	0	0	0	0	0	0	0	0
C16-C30	0	0	0	0	0	0	0	1900	480	480	1400	0	0
Water	0	0	0	0	0	200	200	0	0	0	0	2700	2700
Total	640	410	410	160	250	200	200	1900	480	480	1400	2700	2700

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



Reference Drawings:

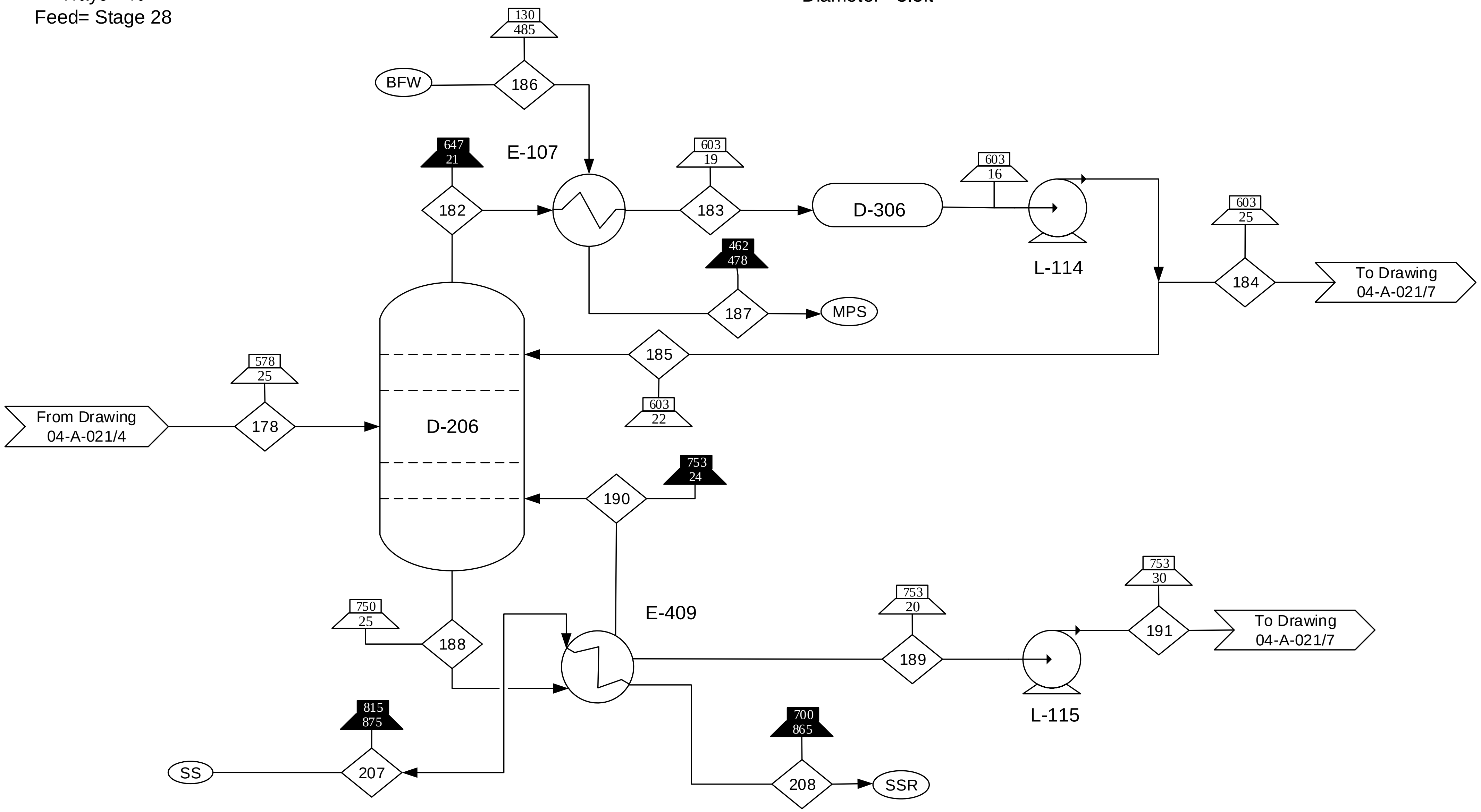
Input/Output Diagam 00-A-019
Block Flow Diagram 00-A-020
Process Flow Diagrams 04-A-021

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	04-A-021/4	0

D-206	E-409 A/B	E-107 A/B	D-306	L-114 A/B	L-115 A/B
Diesel Fuel Oil Cut Height= 120 ft Diameter= 9 ft Trays= 40 Feed= Stage 28	Diesel Fuel Oil Cut Reboiler Area= 2100 ft^2 Duty= 7.5x10^6 Btu/hr	Diesel Fuel Oil Cut Condenser Area= 160 ft^2 Duty= 7.5x10^6 Btu/hr	Diesel Fuel Oil Cut Reflux Drum Length= 14ft Diameter= 3.5ft	Diesel Fuel Oil Cut Reflux Power= 9 hp	Diesel Fuel Oil Cut Bottoms Power= 1 hp



Component/Stream (lb/min)	178	182	183	184	185	186	187	188	189	190	191	207	208
C16-C30	480	0	0	0	0	0	0	0	0	0	0	0	0
C16-C21	0	830	830	470	360	0	0	0	0	0	0	0	0
C22-C30	0	0	0	0	0	0	0	1400	10	1400	9	0	0
Water	0	0	0	0	0	120	120	0	0	0	0	1700	1700
Total	480	830	830	470	360	120	120	1400	10	1400	9	1700	1700

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas
- MPS: Medium Pressure Steam
- BFW: Boiler Feed Water
- SS: Superheated Steam
- SSR: Superheated Steam Recycle

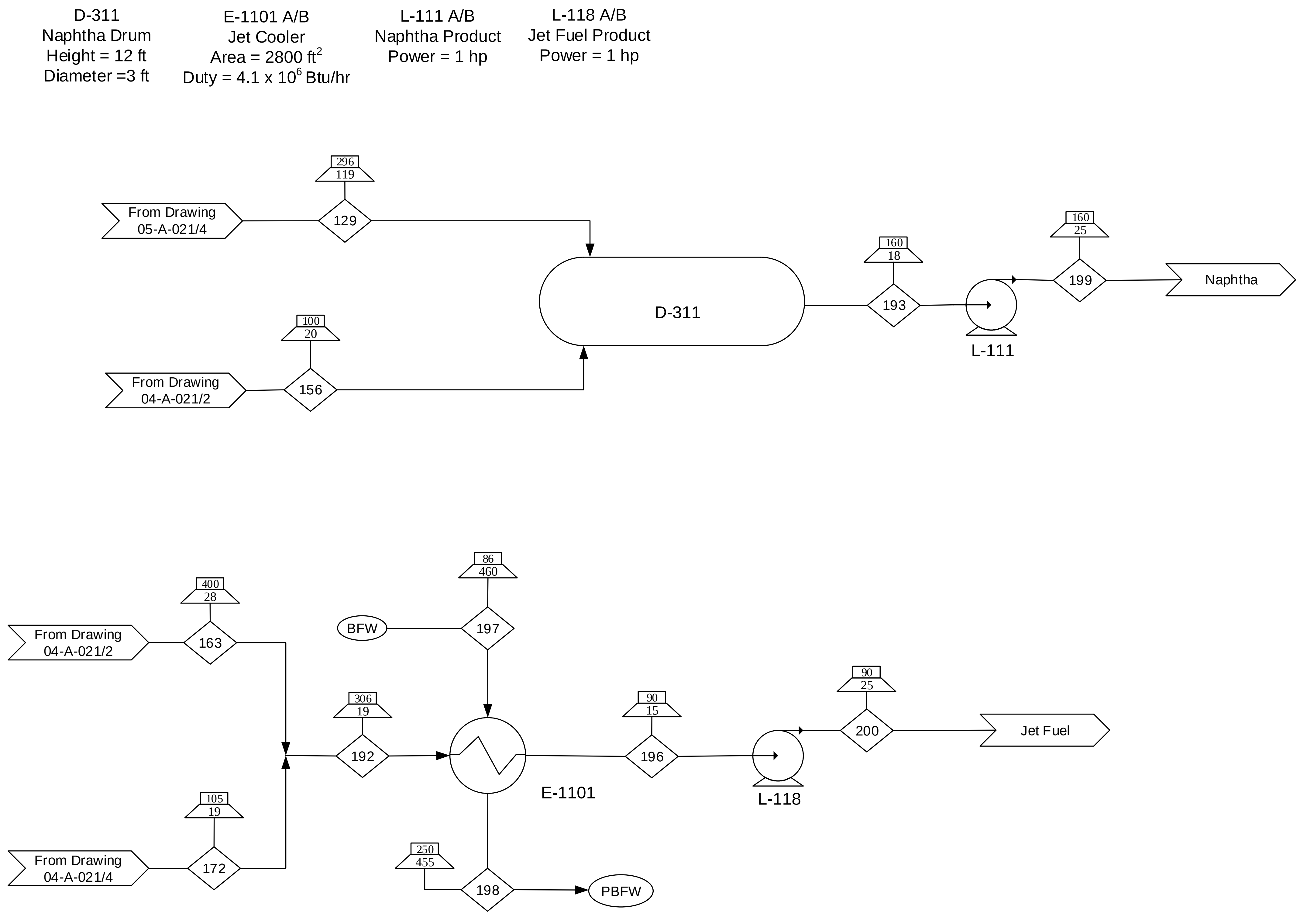
Reference Drawings:

Input/Output Diagram 00-A-019
Block Flow Diagram 00-A-020
Process Flow Diagrams 04-A-021

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design– Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	04-A-021/5	0



Component/Stream (lb/min)	129	156	163	172	192	193	196	197	198	199	200
Naphtha Product	140	140	0	0	0	280	0	0	0	280	0
Jet Fuel Product	0	0	300	160	470	0	470	0	0	0	470
Water	0	0	0	0	0	0	0	250	250	0	0
Total	140	140	300	160	470	280	470	250	250	280	470

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas
- BFW Boiler Feed Water
- PBFW Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram 00-A-019
Block Flow Diagram 00-A-020
Process Flow Diagrams 04-A-021, 05-A-021

Drawing Type
Process Flow Diagram

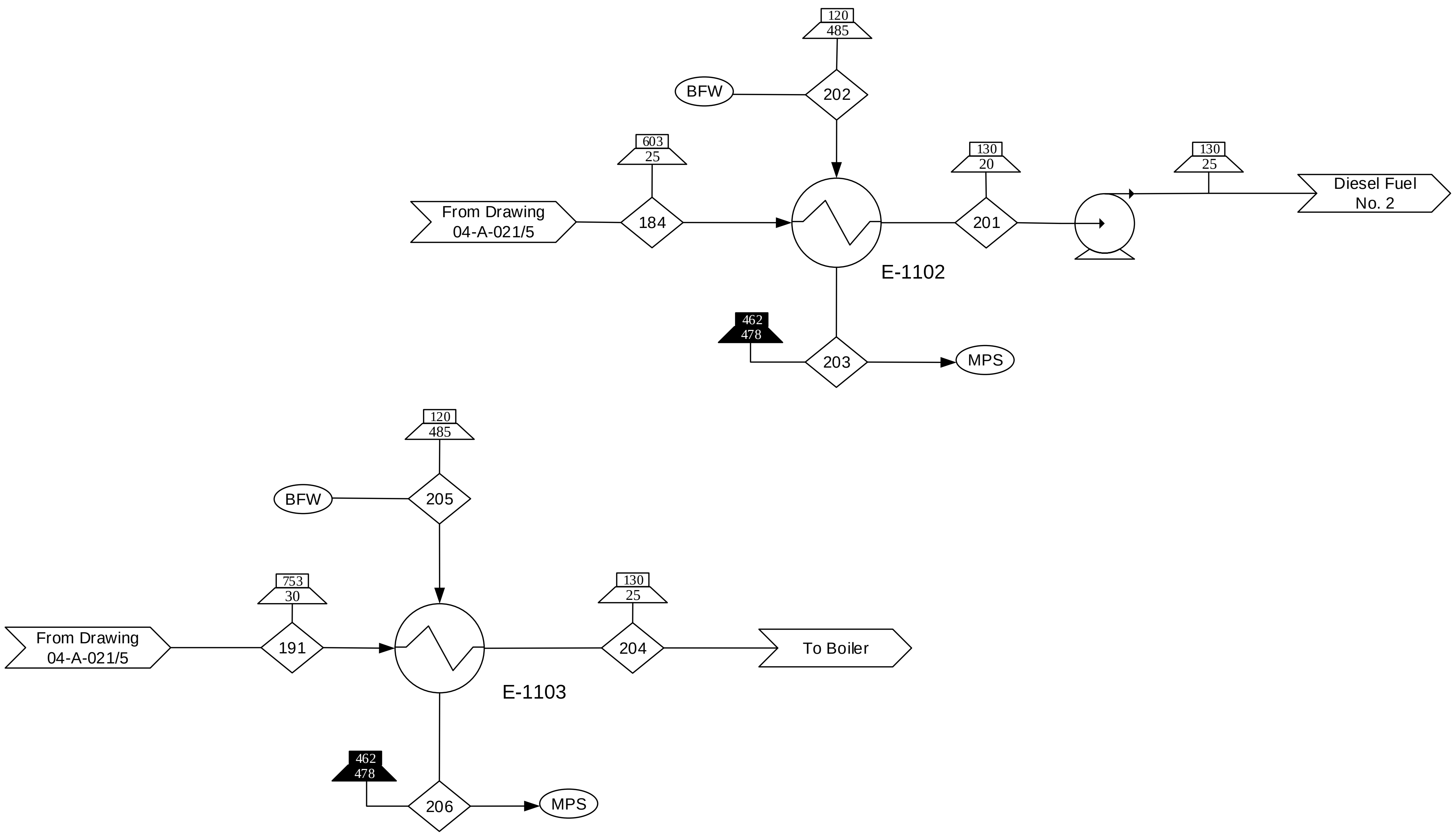
Title
Biorefinery Base Design– Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	04-A-021/6	0

E-1102 A/B
Diesel Cooler
Area = 1400 ft^2
Duty = 1.1 x 10^7 Btu/hr

E-1103 A/B
Fuel Oil Cooler
Area = 64 ft^2
Duty = 2.7 x 10^5 Btu/hr

L-129 A/B
Diesel Product
Power = 1 hp

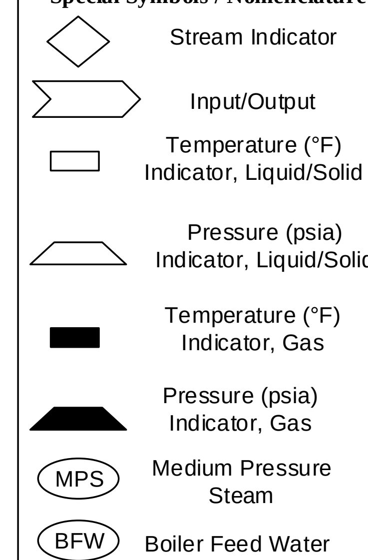


Component/Stream (lb/min)	184	191	201	202	203	204	205	206
Diesel Fuel No. 2 Product	470	0	470	0	0	0	0	0
Fuel Oil No. 5 Product	0	9	0	0	0	9	0	0
Water	0	0	0	160	160	0	5	5
Total	470	9	470	160	160	9	5	5

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagram
00-A-019
Block Flow Diagram
00-A-020
Process Flow Diagrams
04-A-021

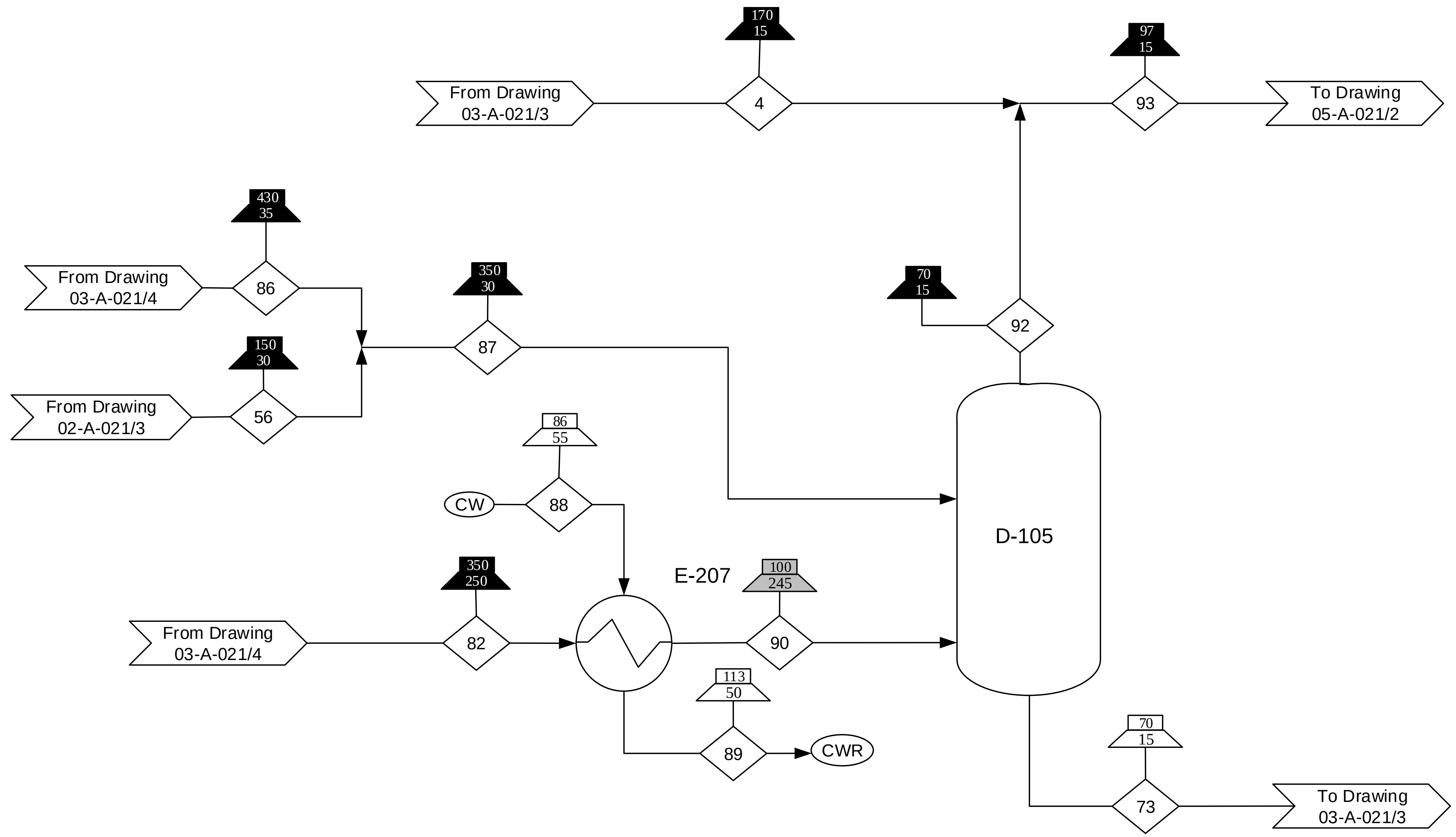
Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design– Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	04-A-021/7	0

D-105
Flash 5
Height= 18 ft
Diameter= 4.5 ft

E-207 A/B
Pre-Flash 5 Cooler
Area= 440 ft^2
Duty= $1.4x10^6$ Btu/hr



Component/Stream (lb/min)	4	56	73	82	86	87	88	89	90	92	93
C1-C2	0	0	0	53	0	0	0	0	53	0	0
C3-C7	0	0	0	0	23	0	0	0	0	0	0
C1-C7	0	0	0	0	0	0	0	0	0	0	0
C1-C6	120	380	0	0	0	400	0	0	0	410	530
C6-C7	0	0	50	0	0	0	0	0	0	0	0
Water	0	0	0	0	0	0	83	83	0	0	0
Total	120	380	50	53	23	400	83	83	53	410	530

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
CW Cooling Water
CWR Cooling Water Recycle

Reference Drawings:

Input/Output Diagram
00-A-019
Block Flow Diagram
00-A-020
Process Flow Diagrams
02-A-021
03-A-021
05-A-021

Drawing Type
Process Flow Diagram

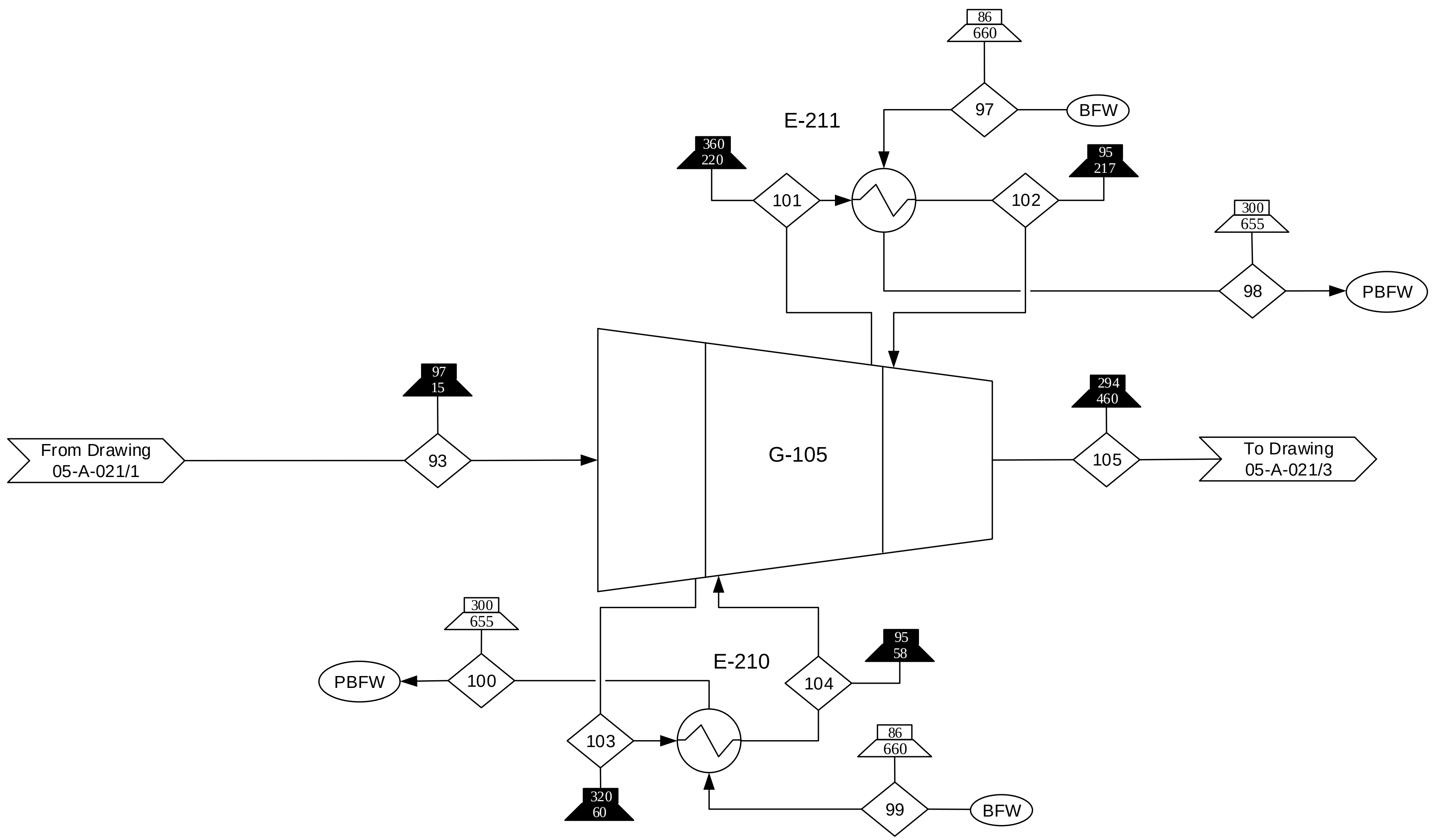
Title
Biorefinery Base Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	05-A-021/1	0

G-105
Light End Compressor
3 Stages
Stage 1 Power= 830 hp
Stage 2 Power = 830 hp
Stage 3 Power = 830 hp

E-210 A/B
Interstage Cooler 1
Area= 2300 ft^2
Duty= $2.5x10^6$ Btu/hr

E-211 A/B
Interstage Cooler 2
Area= 1400 ft^2
Duty= $3.0x10^6$ Btu/hr



Component/Stream (lb/min)	93	97	98	99	100	101	102	103	104	105
C1-C6	530	0	0	0	0	530	530	530	530	530
Water	0	180	180	150	150	0	0	0	0	0
Total	530	180	180	150	150	530	530	530	530	530

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in lb/min.

4. Pumps operate at 65% efficiency.

5. Compressors operate at 55% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-019
Block Flow Diagram
00-A-020
Process Flow Diagrams
05-A-021

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	05-A-021/2	0

D-207
Syngas Column
Height= 120 ft
Diameter= 9 ft
Trays= 40
Feed= Stage 5

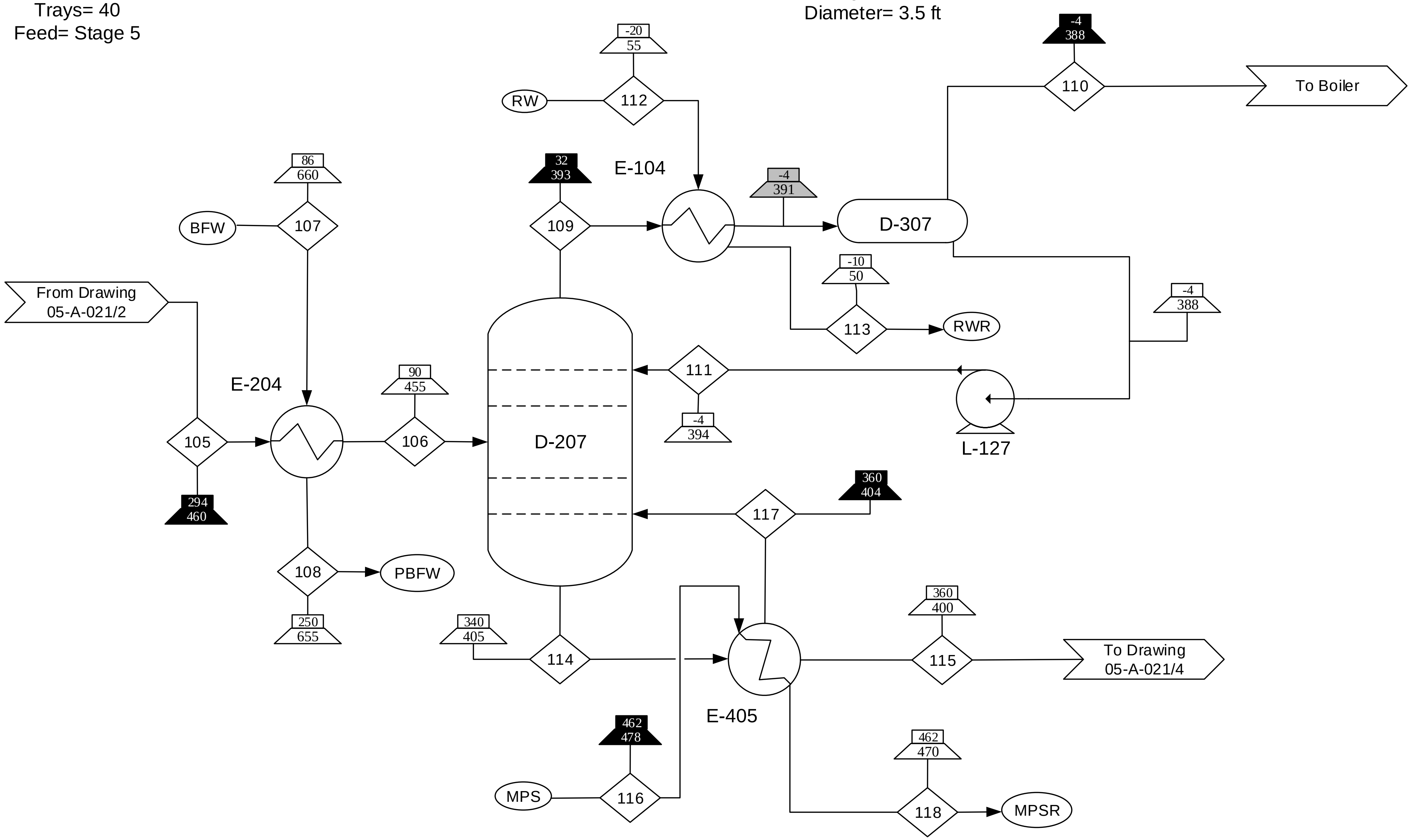
E-204 A/B
Syngas Cooler
Area= 3900 ft^2
Duty= $4.8x10^6$ Btu/hr

E-104 A/B
Syngas Condenser
Area= 820 ft^2
Duty= $2.0x10^6$ Btu/hr

E-405 A/B
Syngas Reboiler
Area= 210 ft^2
Duty= $3.5x10^6$ Btu/hr

D-307
Syngas Column
Reflux Drum
Length= 14 ft
Diameter= 3.5 ft

L-127 A/B
Syngas Column Reflux
Power= 8 hp



Component/Stream (lb/min)	105	106	107	108	109	110	111	112	113	114	115	116	117	118
C1-C6	530	540	0	0	0	0	0	0	0	0	0	0	0	0
C1-C3	0	0	0	0	520	350	170	0	0	0	0	0	0	0
C4-C6	0	0	0	0	0	0	0	0	0	770	180	0	590	0
Water	0	0	290	290	0	0	0	1200	1200	0	0	75	0	75
Total	530	540	290	290	520	350	170	1200	1200	770	180	75	590	75

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
MPS – Medium Pressure Steam
MPSR – Medium Pressure Steam Recycle
RW – Refrigerated Water
RWR – Refrigerated Water Recycle
BFW – Boiler Feed Water
PBFW – Preheated Boiler Feed Water

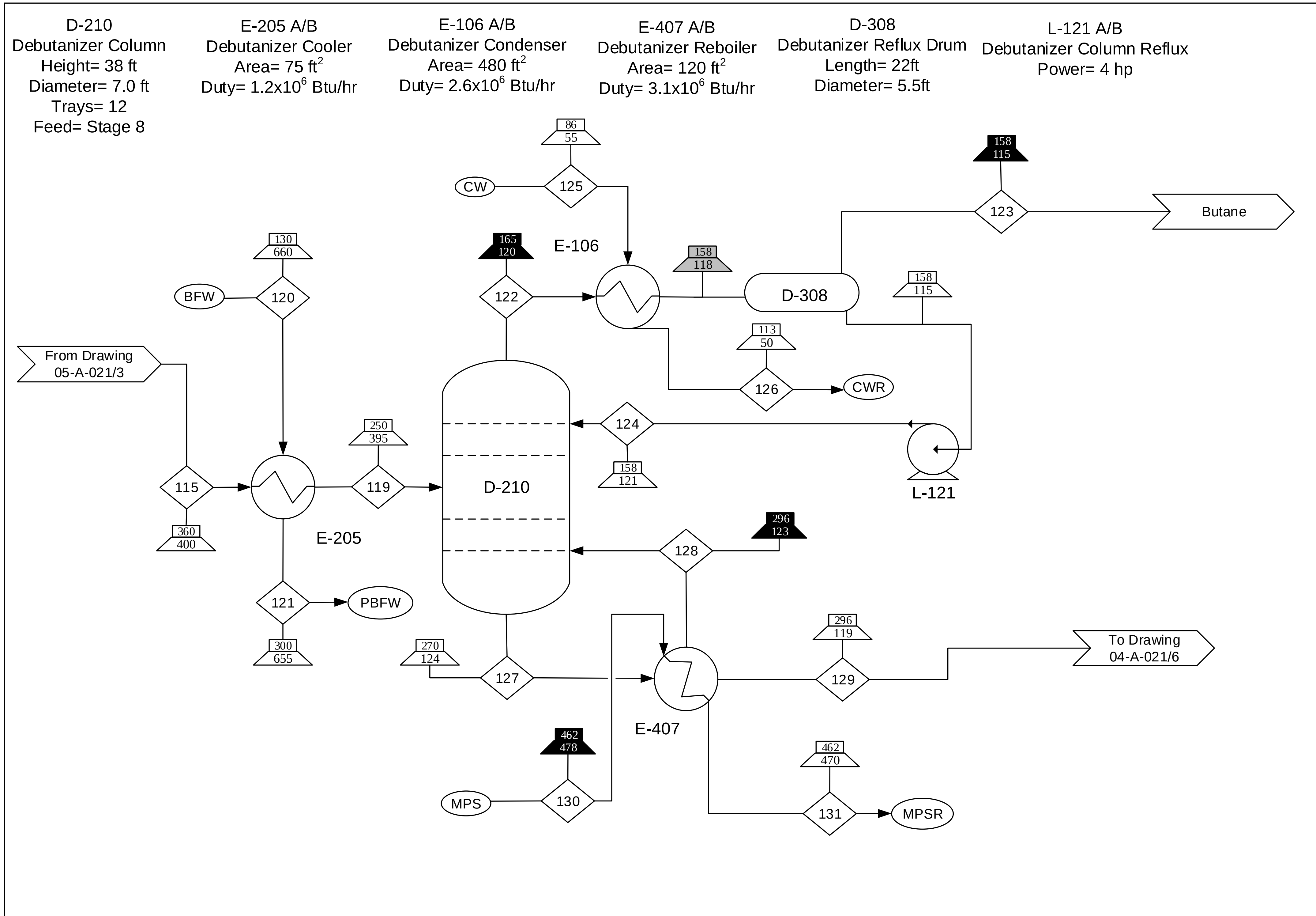
Reference Drawings:

Input/Output Diagram
00-A-019
Block Flow Diagram
00-A-020
Process Flow Diagrams
05-A-021

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design– Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	05-A-021/3	0



Component/Stream (lb/min)	115	119	120	121	122	123	124	125	126	127	128	129	130	131
C4-C6	180	180	0	0	0	0	0	0	0	0	0	0	0	0
Butane	0	0	0	0	340	46	290	0	0	0	0	0	0	0
C5-C6	0	0	0	0	0	0	0	0	0	500	360	140	0	0
Water	0	0	71	71	0	0	0	160	160	0	0	0	68	68
Total	180	180	71	71	340	46	290	160	160	500	360	140	68	68

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
5. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
MPS Medium Pressure Steam
MPSR Medium Pressure Steam Recycle
CW Cooling Water
CWR Cooling Water Recycle
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

Reference Drawings:

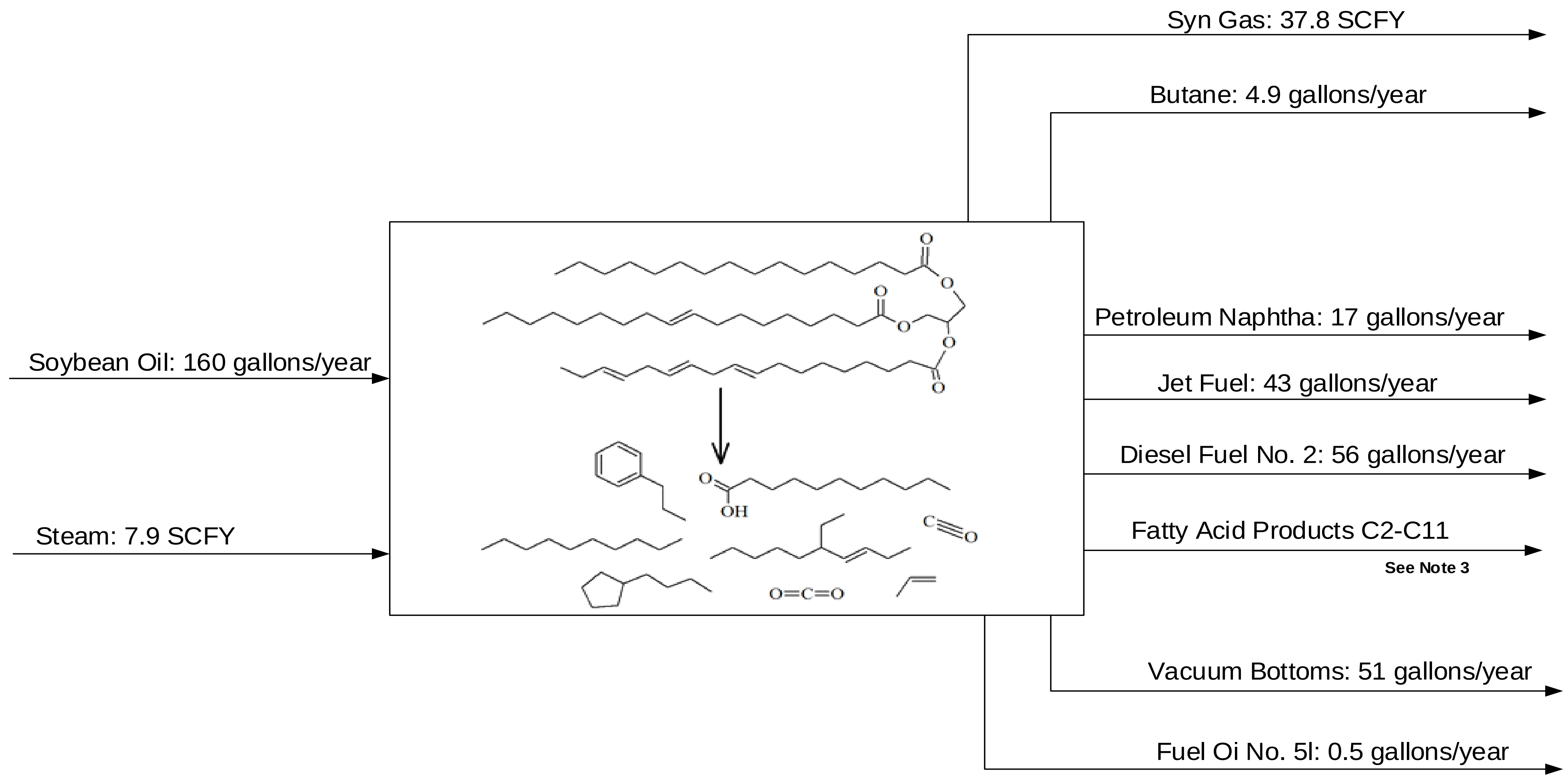
Input/Output Diagram 00-A-019
Block Flow Diagram 00-A-020
Process Flow Diagrams 04-A-021, 05-A-021

Drawing Type: Process Flow Diagram

Title: Biorefinery Base Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-24-17	05-A-021/4	0

I.2. Fatty Acid Recovery Design English Units Drawings



Fatty Acid	1,000,000 gallons/year
Acetic Acid	0.71
Propionic Acid	0.082
Butyric Acid	0.17
Valeric Acid	0.5
Caproic Acid	0.98
Heptanoic Acid	2.6
Octanoic Acid	1.9
Nananoic Acid	2.2
Decanoic Acid	2
Undecanoic Acid	0.82

Notes

1. Material balance may be off due to rounding errors.

2. Material balance is shown in 1,000,000 units/year.

3. See table below for fatty acid product production.

Special Symbols / Nomenclature

Reference Drawings:

Block Flow Diagram
00-A-005

Process Flow Diagram
00-A-006

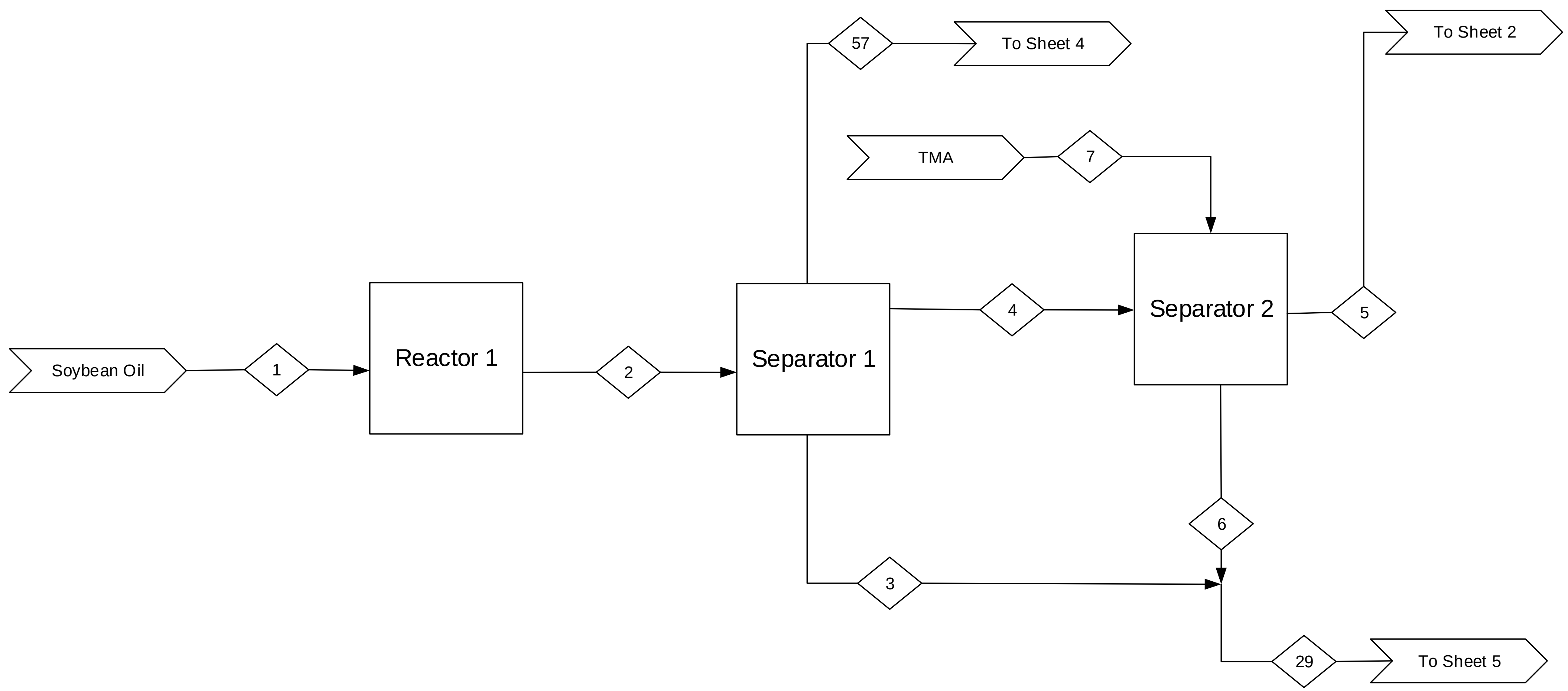
Drawing Type

Input/Output Diagram

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 2/14/17	00-A-004/1	0



Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 1: Cracking incoming TG oil into fuel intermediates

Separator 1: Separate aqueous acetic acid from organic crackate

Separator 2: Separate fatty acids from organic liquid product through solvent extraction

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-004

Process Flow Diagram
00-A-006

Drawing Type

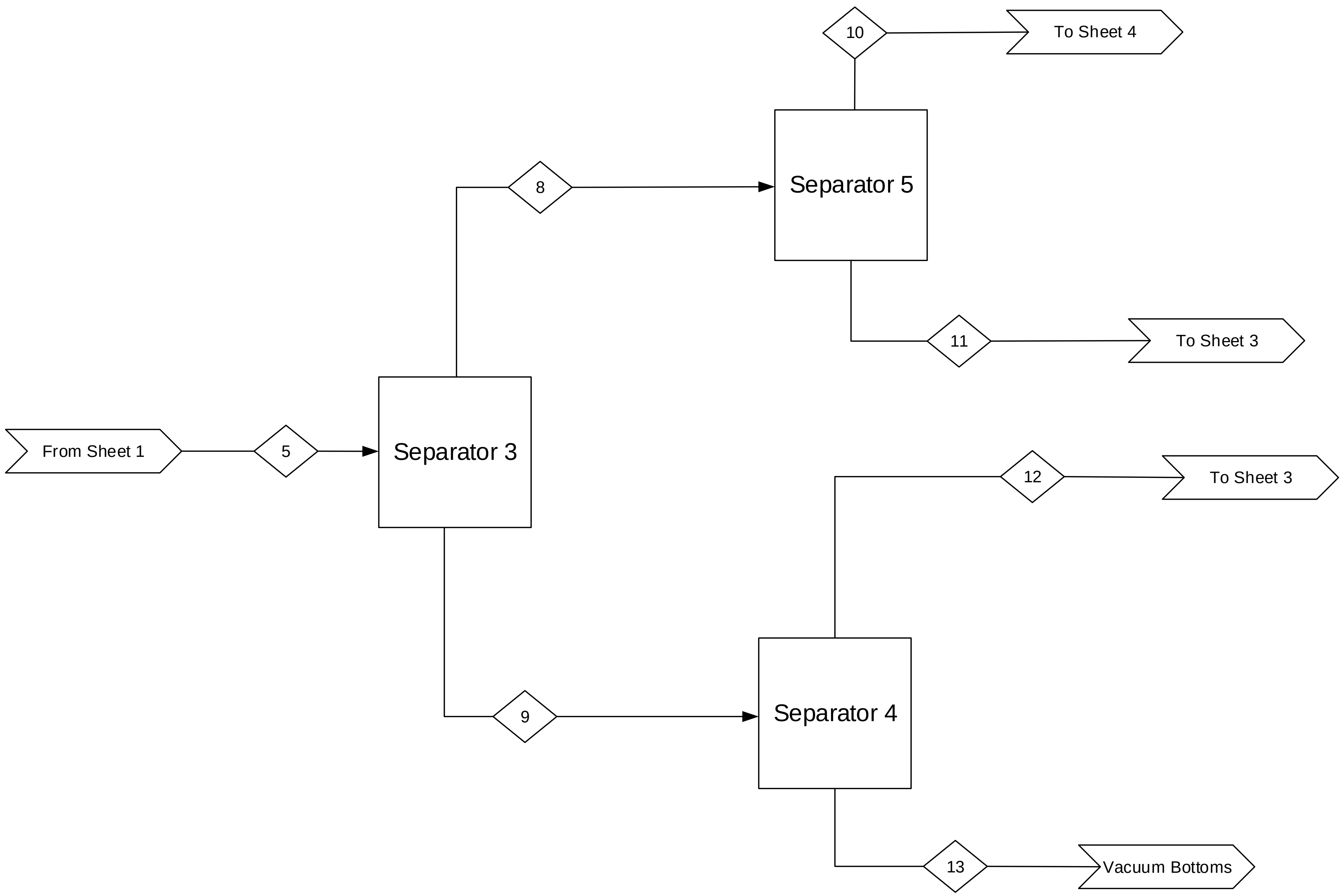
Quantitative BFD

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 2-15-17	00-A-005/1	0

Component/Stream (lb/min)	1	2	3	4	5	6	7	29	57
Soybean Oil	2200	0	0	0	0	0	0	0	0
C1-C50	0	2200	0	1800	1400	0	0	0	0
Fatty Acids C2-C17	0	0	0	0	0	280	0	280	0
Acetic Acid	0	0	6	0	0	5	0	11	0
C1-C6	0	0	0	0	0	0	0	0	360
TMA	0	0	0	0	0	340	340	340	0
Water	0	0	0	0	0	1360	1360	1360	0
Total	2200	2200	6	1800	1400	2000	1700	2000	360



Component/Stream (lb/min)	5	8	9	10	11	12	13
C1-C50	1400	0	0	0	0	0	0
C9-C50	0	0	1100	0	0	0	0
C1-C15	0	440	0	0	0	0	0
C1-C5	0	0	0	14	0	0	0
C5-C15	0	0	0	0	430	0	0
C9-C30	0	0	0	0	0	550	0
C30-C50	0	0	0	0	0	0	560
Total	1400	440	1100	14	430	550	560

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

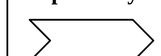
6. Assume 100% separation in separators.

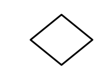
7. Separator 3: Separate naphtha range fuel intermediates from diesel range fuel intermediates

Separator 4: Separate diesel fuel range intermediates from vacuum bottoms byproduct

Separator 5: Separate light ends from naphtha range fuel intermediates

Special Symbols / Nomenclature


Input/Output


Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-004

Process Flow Diagram
00-A-006

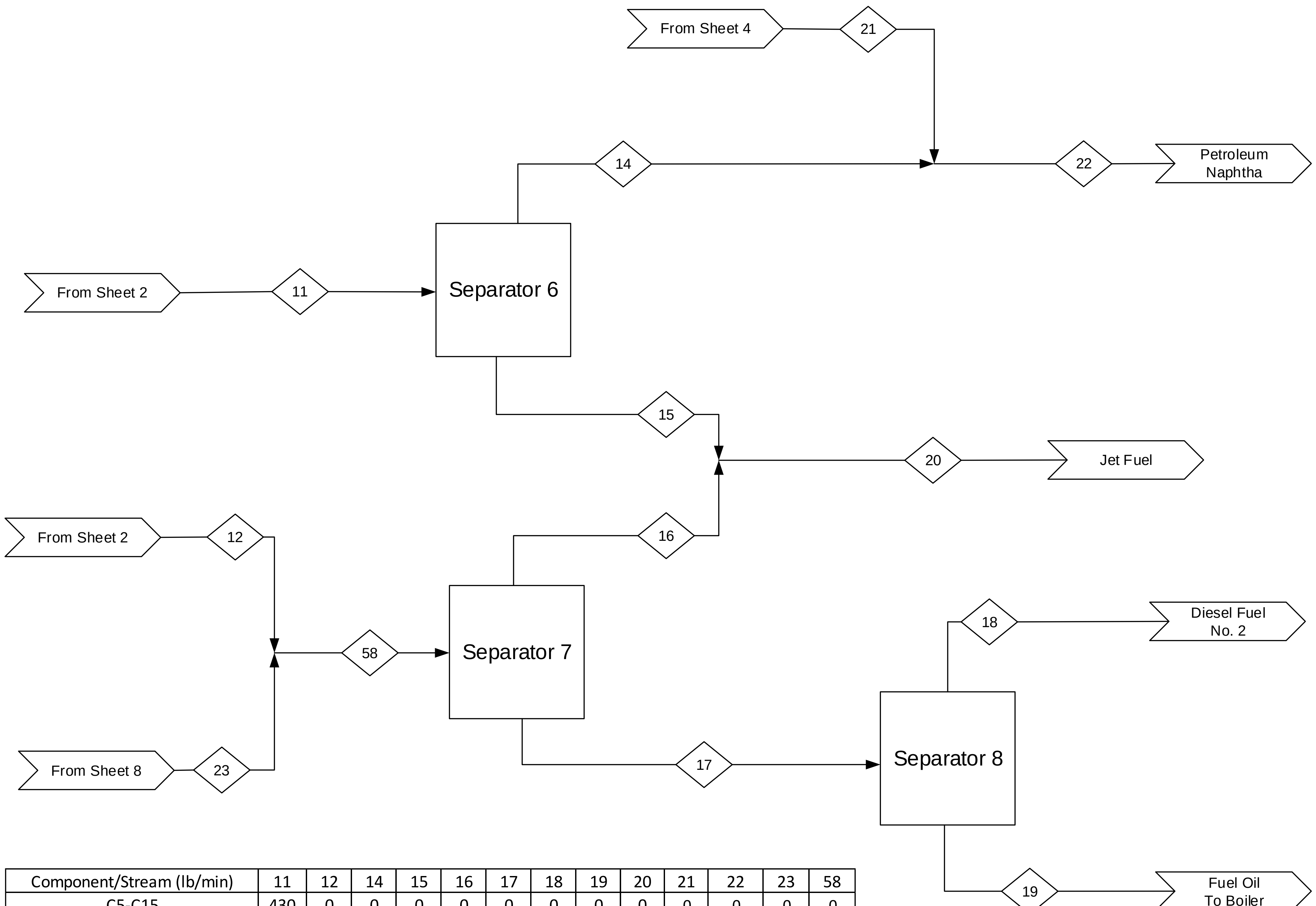
Drawing Type

Quantitative BFD

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 2-15-17	00-A-005/2	0



Component/Stream (lb/min)	11	12	14	15	16	17	18	19	20	21	22	23	58
C5-C15	430	0	0	0	0	0	0	0	0	0	0	0	0
C5-C8	0	0	100	0	0	0	0	0	0	85	190	0	0
C9-C15	0	0	0	330	140	0	0	0	460	0	0	110	0
C15-C22	0	0	0	0	0	0	520	0	0	0	0	0	0
C15-C30	0	0	0	0	0	530	0	0	0	0	0	0	0
C23-C30	0	0	0	0	0	0	0	5	0	0	0	0	0
C9-C30	0	550	0	0	0	0	0	0	0	0	0	0	670
Total	430	550	100	330	140	530	520	5	460	85	190	110	670

Notes

1. Drawing not to scale.
2. Mass balance may be off due to rounding.
3. Stream numbers do not correspond with PFD stream numbers.
4. Mass balances shown in lb/min.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Assume 100% separation in separators.
7. Separator 6: Separate naphtha product from jet fuel product

Separator 7: Separate jet fuel product from diesel and fuel oil range intermediates

Separator 8: Separate diesel fuel no. 2 product from fuel oil no. 5 by product

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-004

Process Flow Diagram
00-A-006

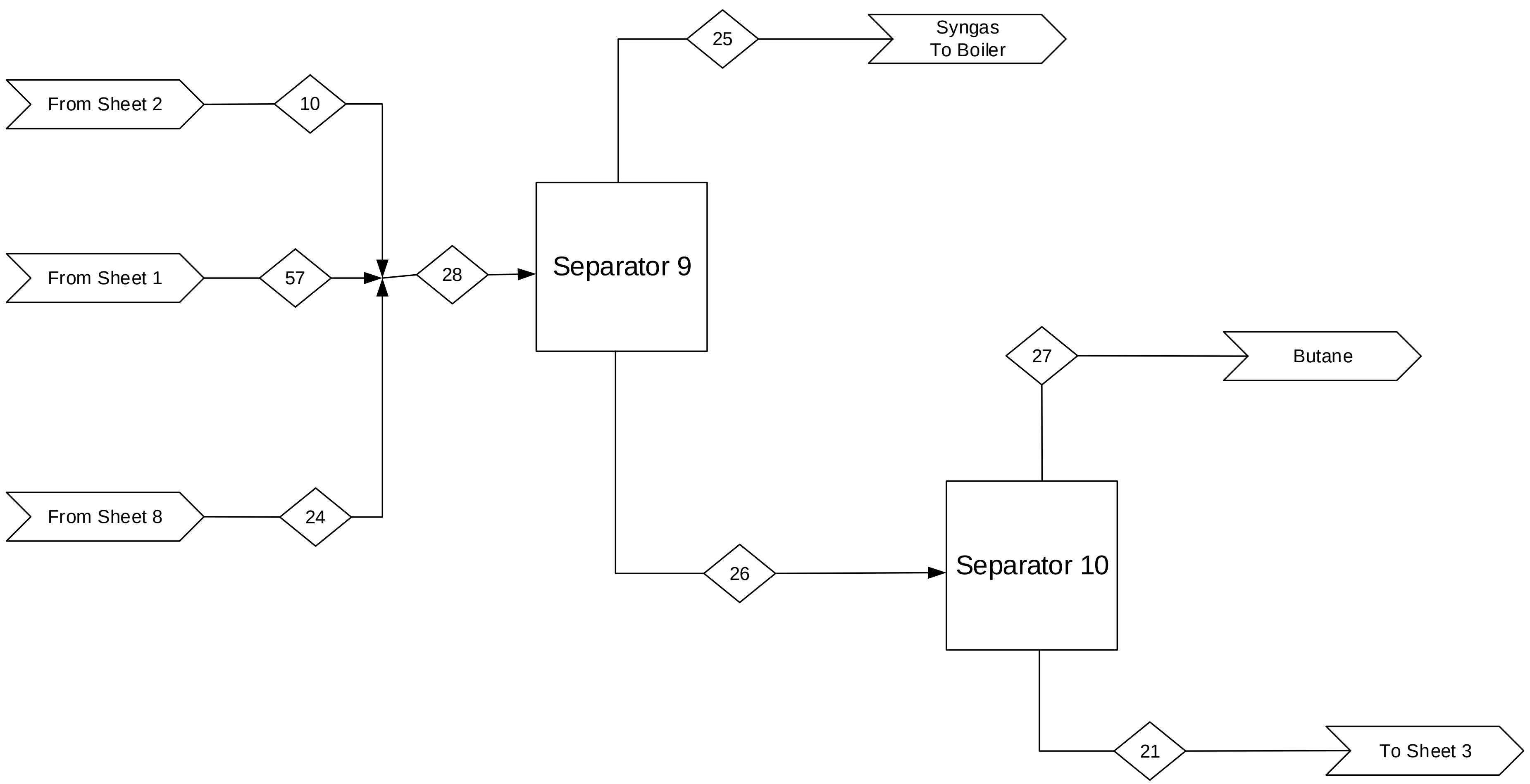
Drawing Type

Quantitative BFD

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 02-15-17	00-A-005/3	0



Component/Stream (lb/min)	10	21	24	25	26	27	28	57
C1-C6	0	0	0	0	0	0	0	360
C1-C10	0	0	30	0	0	0	400	0
C1-C3	0	0	0	270	0	0	0	0
Butane	0	0	0	0	0	42	0	0
C4-C10	0	0	0	0	130	0	0	0
C5-C10	0	85	0	0	0	0	0	0
C1-C5	14	0	0	0	0	0	0	0
Total	14	85	30	270	130	42	400	360

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

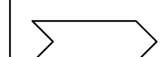
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

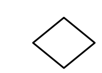
7. Separator 9: Separate boiler fuel (syngas) from heavier light ends

Separator 10. Separate butane byproduct from naphtha product

Special Symbols / Nomenclature



Input/Output



Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-004

Process Flow Diagram
00-A-006

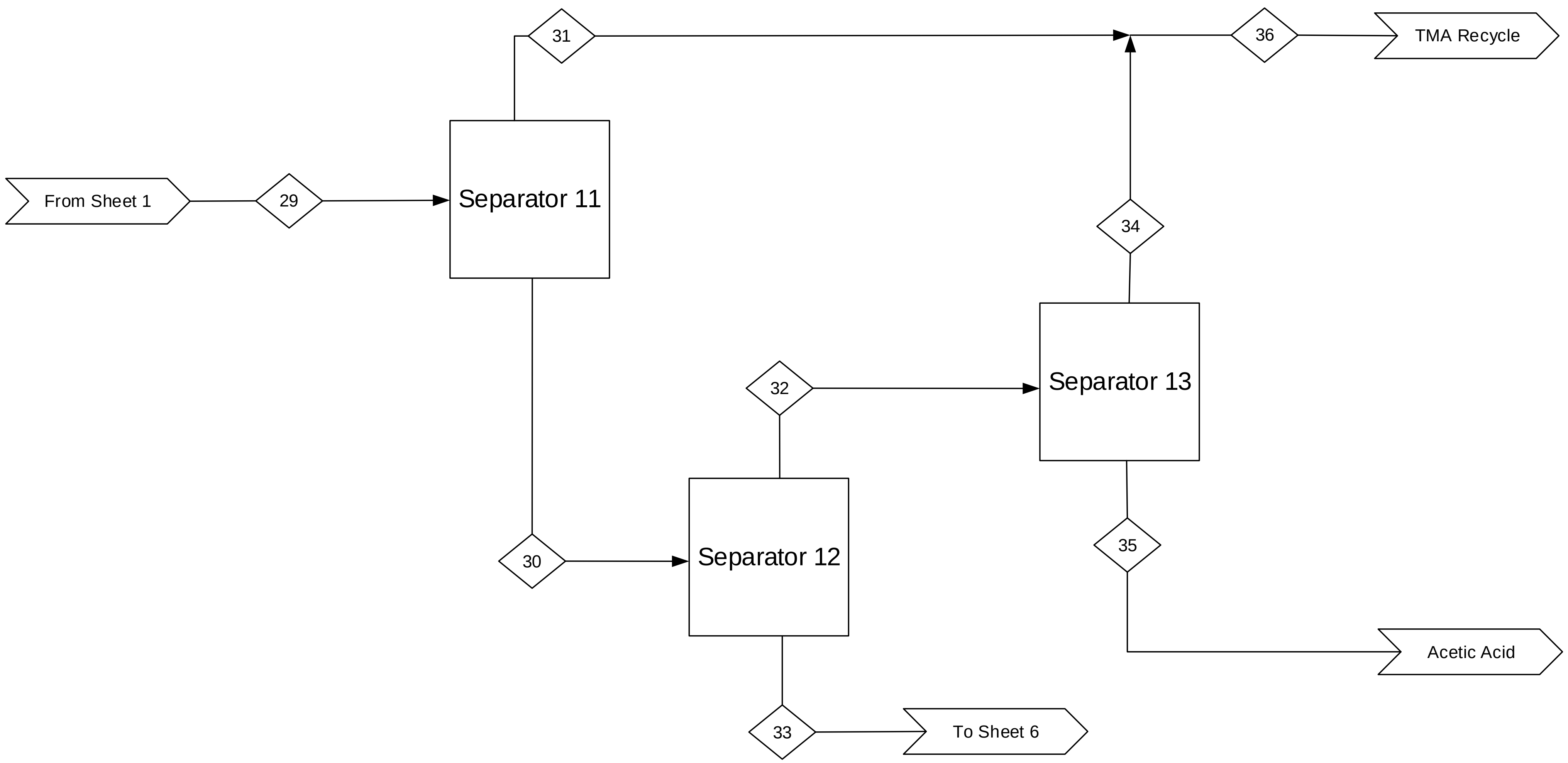
Drawing Type

Quantitative BFD

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 02-15-17	00-A-005/4	0



Component/Stream (lb/min)	29	30	31	32	33	34	35	36
TMA	340	0	340	0	0	0	0	340
Water	1360	68	1300	68	0	68	0	1360
Fatty Acids C2-C17	0	0	0	0	0	0	0	0
Fatty Acids C3-C17	280	280	0	0	280	0	0	0
Acetic Acid	11	11	0	11	0	0	11	0
Total	2000	360	1600	79	280	68	11	1700

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Separator 11: Removes all of the solvent and the majority of water from the fatty acids

Separator 12: Separates remaining water and acetic acid from heavier fatty acids

Separator 13. Separates acetic acid by product from water

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-004

Process Flow Diagram
00-A-006

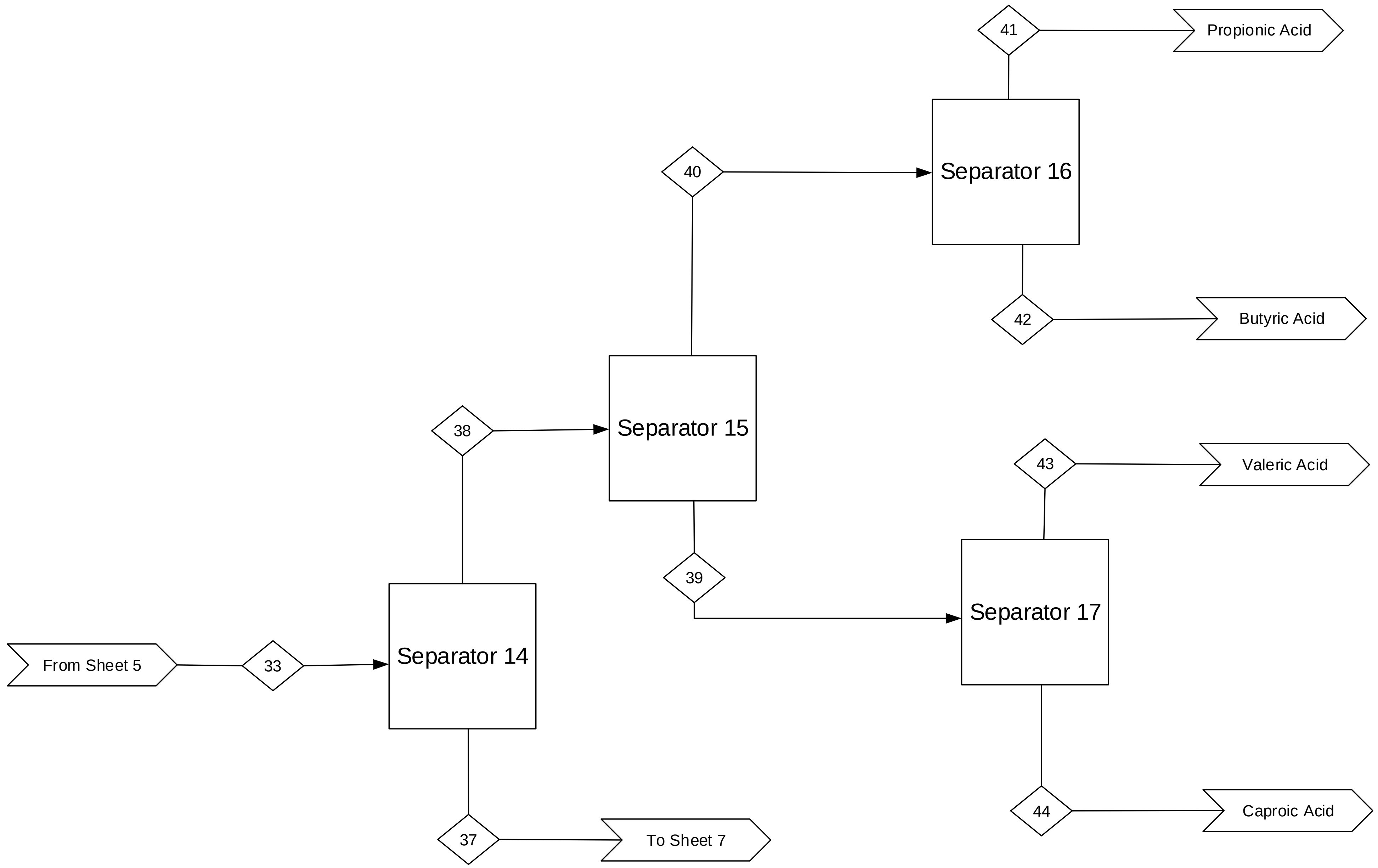
Drawing Type

Quantitative BFD

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 02-15-17	00-A-005/5	0



Component/Stream (lb/min)	33	37	38	39	40	41	42	43	44
Fatty Acids C3-C17	280	0	0	0	0	0	0	0	0
Fatty Acids C3-C6	0	0	23	0	0	0	0	0	0
Fatty acids C7-C17	0	260	0	0	0	0	0	0	0
Fatty Acids C3-C4	0	0	0	0	4	0	0	0	0
Propionic Acid	0	0	0	0	0	1	0	0	0
Butyric Acid	0	0	0	0	0	0	3	0	0
Fatty Acids C5-C6	0	0	0	19	0	0	0	0	0
Valeric Acid	0	0	0	0	0	0	0	7	0
Caproic Acid	0	0	0	0	0	0	0	0	12
Total	280	260	23	19	4	1	3	7	12

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

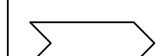
7. Separator 14: Separate C6 and lighter fatty acids from C7 and heavier fatty acids

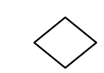
Separator 15: Separate C3-C4 fatty acids from C5-C6 fatty acids

Separator 16: Separate propionic acid byproduct from butyic acid byproduct

Separator 17: Separate valeric acid byproduct from caproic acid byproduct

Special Symbols / Nomenclature


Input/Output


Stream Indicator

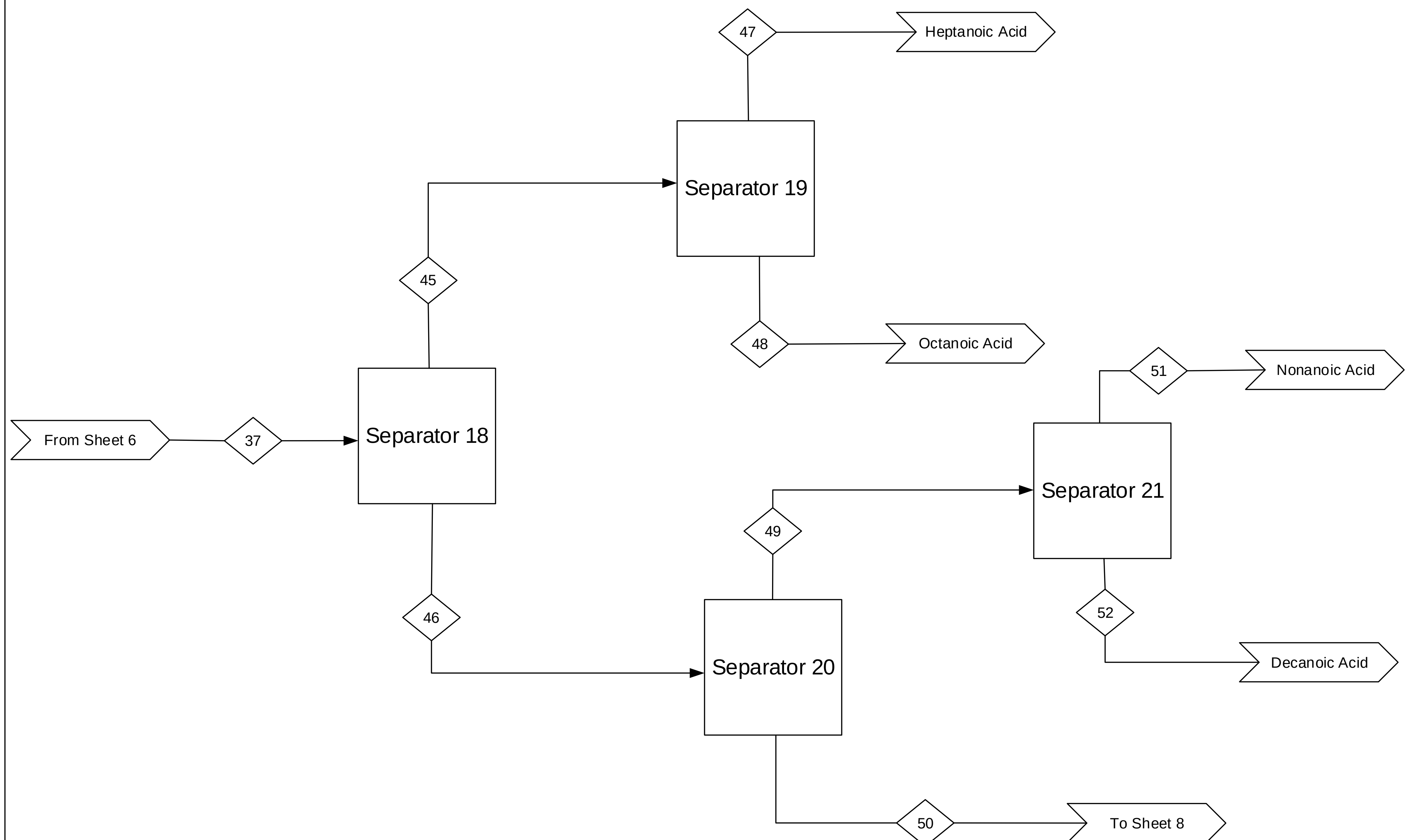
Reference Drawings:
Input/Output Diagram
00-A-004

Process Flow Diagram
00-A-006

Drawing Type
Quantitative BFD

Title
Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 02-15-17	00-A-005/6	0



Component/Stream (lb/min)	37	45	46	47	48	49	50	51	52
Fatty Acids C7-C17	260	0	0	0	0	0	0	0	0
Fatty Acids C7-C8	0	57	0	0	0	0	0	0	0
Heptanoic Acid	0	0	0	33	0	0	0	0	0
Octanoic Acid	0	0	0	0	24	0	0	0	0
Fatty Acids C9-C17	0	0	200	0	0	0	0	0	0
Fatty Acids C9-C10	0	0	0	0	0	52	0	0	0
Nonanoic Acid	0	0	0	0	0	0	0	27	0
Decanoic Acid	0	0	0	0	0	0	0	0	25
Fatty Acids C11-C17	0	0	0	0	0	0	150	0	0
Total	260	57	200	33	24	52	150	27	25

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Separator 18: Separate C7-C8 fatty acids from C9-C18 fatty acids

Separator 19: Separate heptanoic acid byproduct from octanoic acid byproduct

Separator 20: Separate C9-C10 fatty acids from C11 and heavier fatty acids

Separator 21: Separate nonanoic acid byproduct from decanoic acid byproduct

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-004

Process Flow Diagram
00-A-006

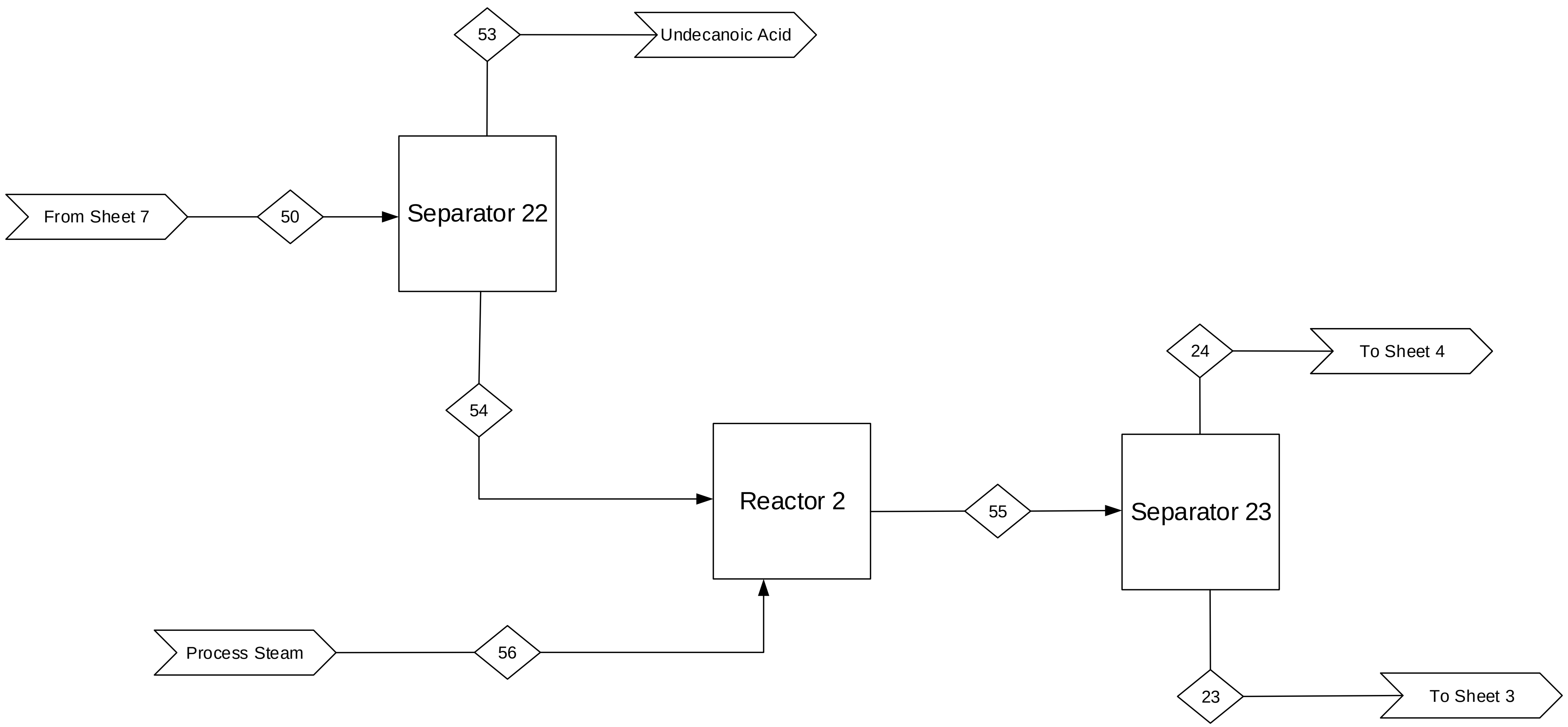
Drawing Type

Quantitative BFD

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 02-15-17	00-A-005/7	0



Component/Stream (lb/min)	23	24	50	53	54	55	56
C1-C17	0	0	0	0	0	140	0
C1-C10	0	30	0	0	0	0	0
C11-C17	110	0	0	0	0	0	0
Fatty Acids C11-C17	0	0	150	0	0	0	0
Fatty Acids C12-C17	0	0	0	0	140	0	0
Undecanoic Acid	0	0	0	10	0	0	0
Water	0	0	0	0	0	0	4
Total	110	30	150	10	140	140	4

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

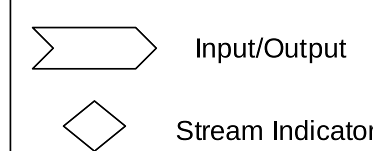
6. Assume 100% separation in separators.

7. Reactor 2: React fatty acids and alkenes with steam to produce hydrocarbons

Separator 22: Separate undecanoic acid byproduct from C12-C18 fatty acids

Separator 23: Separate light ends from diesel fuel range intermediates

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagram 00-A-004

Process Flow Diagram 00-A-006

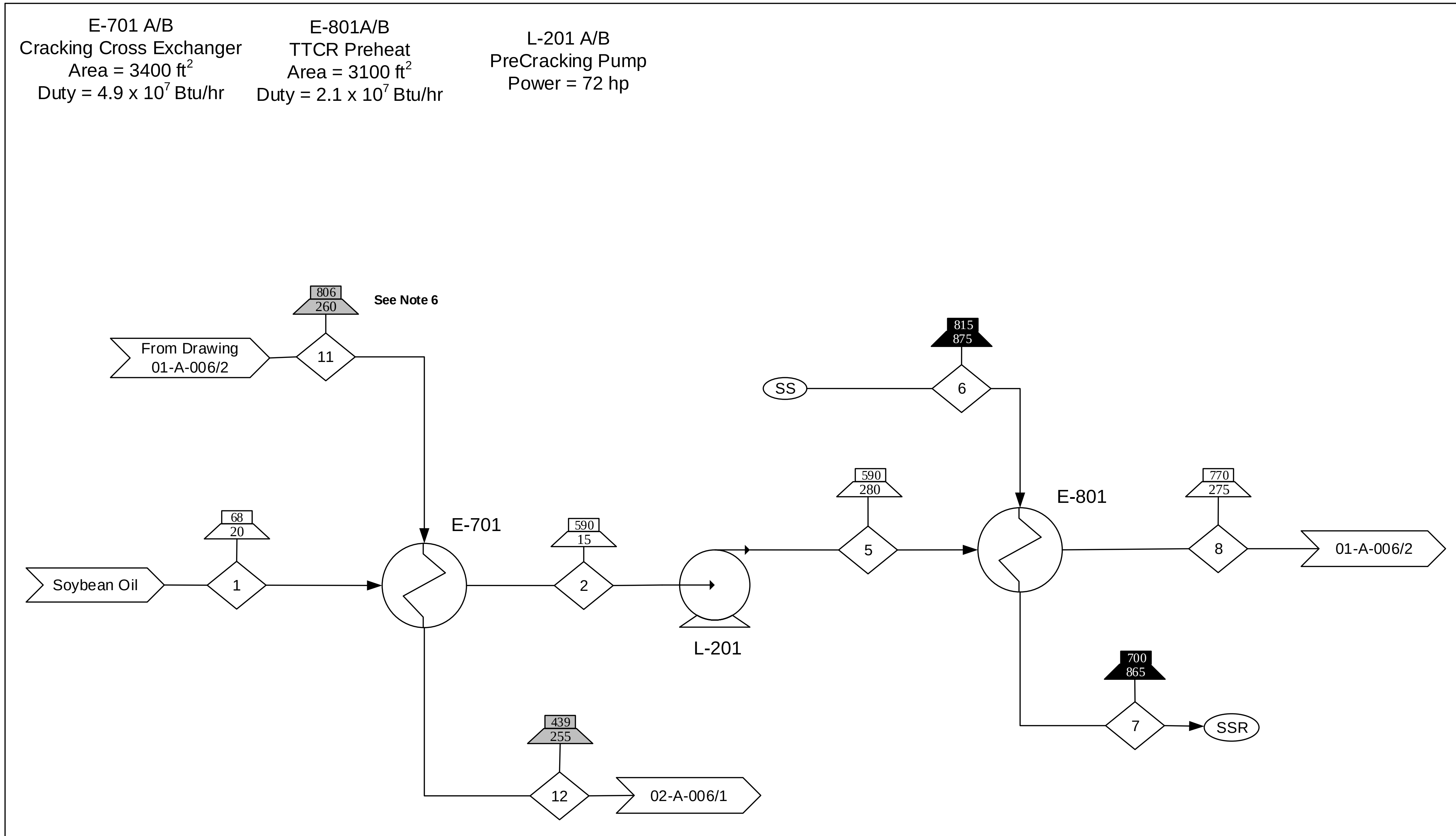
Drawing Type

Quantitative BFD

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Fatty Acid Recovery Design

By/Date	DWG # / Sheet #	Rev
SAB/ 02-15-17	00-A-005/8	0



Component/Stream (lb/min)	1	2	5	6	7	8	11	12
Soybean Oil	2200	2200	2200	0	0	2200	0	0
C1-C50	0	0	0	0	0	0	2200	2200
Water	0	0	0	5300	5300	0	0	0
Total	2200	2200	2200	5300	5300	2200	2200	2200

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 11 and 12 is an organic, aqueous, gaseous three phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
SS Superheated Steam
SSR Superheated Steam Recycle

Reference Drawings:

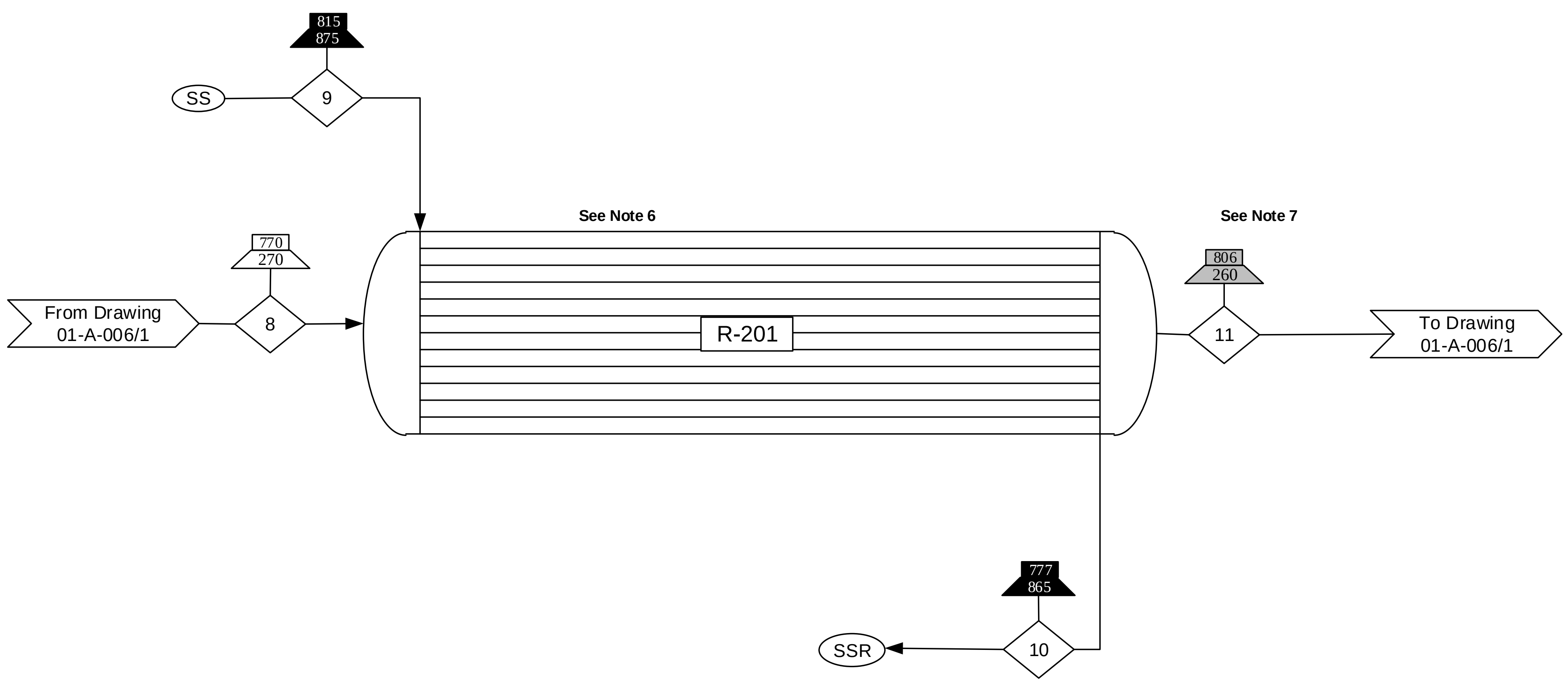
Input/Output Diagram 00-A-004
Block Flow Diagram 00-A-005
Process Flow Diagrams 01-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design- Thermal Cracking Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-25-17	01-A-006/1	0

R-201
TTCR
Diameter= 20 ft
Length= 40 ft
Tubes= 10300



Component/Stream (lb/min)	8	9	10	11
Soybean Oil	2200	0	0	0
C1-C50	0	0	0	2200
Water	0	18000	18000	0
Total	2200	18000	18000	2200

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. R-101 has a residence time of 1.17 hr.
7. Stream 11 is composed of a gas phase stream with entrained liquid tars.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
SS Superheated Steam
SR Superheated Steam Recycle

Reference Drawings:

Input/Output Diagram 00-A-004
Block Flow Diagram 00-A-005
Process Flow Diagrams 01-A-006 02-A-006

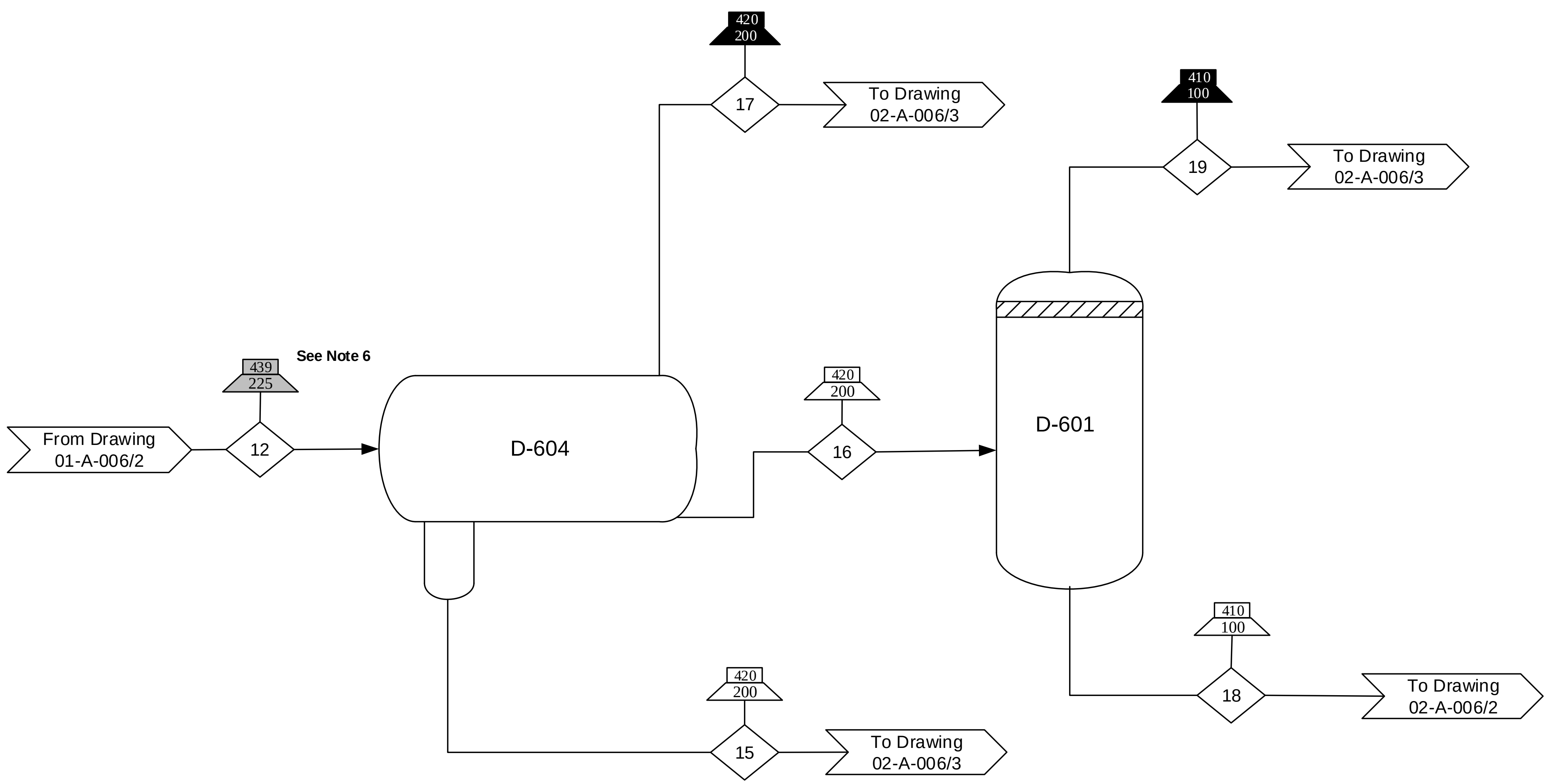
Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design- Thermal Cracking Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-25-17	01-A-006/2	0

D-601
Flash 1
Height= 19 ft
Diameter= 4.5 ft

D-604
Acetic Acid Separator 1
Length= 6 ft
Diameter= 1.5 ft



Component/Stream (lb/min)	12	15	16	17	18	19
C1-C50	2200	0	0	0	0	0
C1-C8	0	0	0	460	0	20
C4-C50	0	0	1700	0	1700	0
Acetic Acid	0	6	0	Trace	0	0
Propionic Acid	0	1	0	0	0	0
Total	2200	7	1700	460	1700	20

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 12 is composed of an aqueous and organic three phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase

Reference Drawings:

Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
01-A-006
02-A-006

Drawing Type
Process Flow Diagram

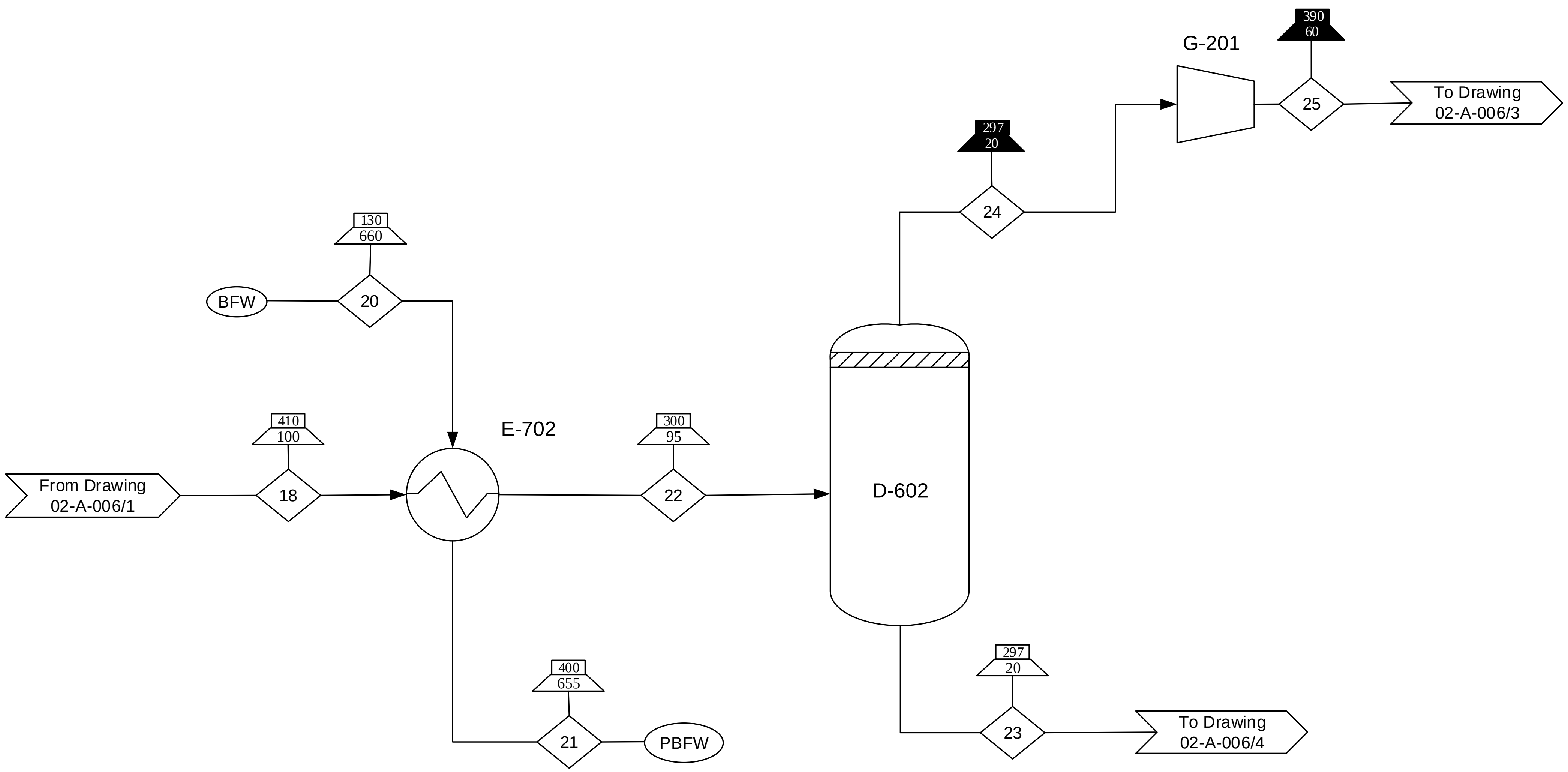
Title
Biorefinery Fatty Acid Recovery Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-25-17	02-A-006/1	0

D-602
Flash 2
Height= 17.5 ft
Diameter= 4.5 ft

E-702 A/B
Flash 2 Cooler
Area= 1800 ft^2
Duty= $9.3x10^6$ Btu/hr

G-201 A/B
Flash 2 Compressor
Power= 22 hp



Component/Stream (lb/min)	18	20	21	22	23	24	25
C1-C8	0	0	0	0	0	20	20
C4-C50	1700	0	0	1700	1700	0	0
Water	0	560	560	0	0	0	0
Total	1700	560	560	1700	1700	20	20

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

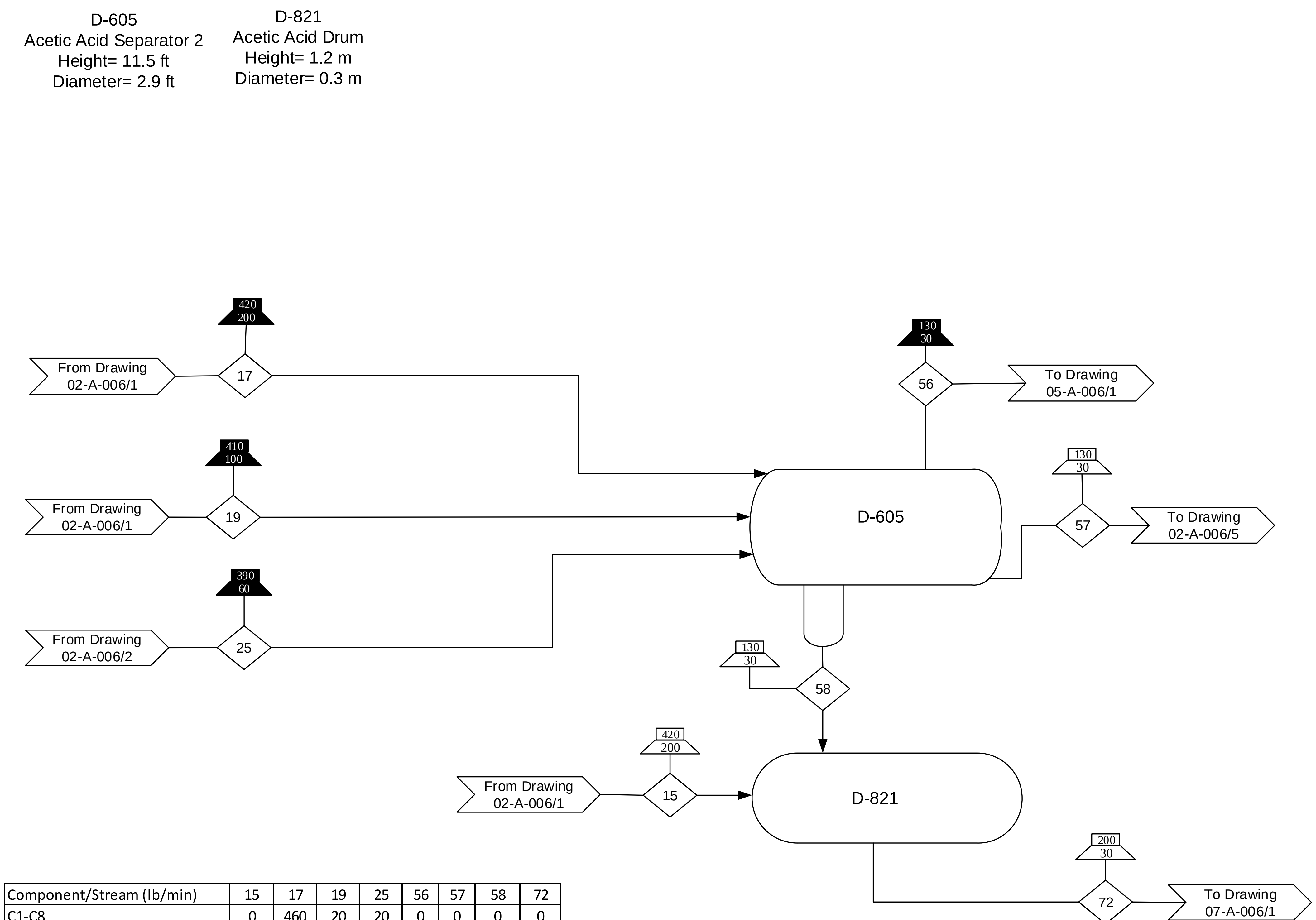
Reference Drawings:

Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
02-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-25-17	02-A-006/2	0



Component/Stream (lb/min)	15	17	19	25	56	57	58	72
C1-C8	0	460	20	20	0	0	0	0
C1-C6	0	0	0	0	380	0	0	0
C6-C8	0	0	0	0	0	120	0	0
Water	0	0	0	0	0	0	0	0
Acetic Acid	6	0	0	0	0	0	3	9
Propionic Acid	1	0	0	0	0	0	Trace	1
Total	7	460	20	20	380	120	3	10

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in lb/min.

4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase

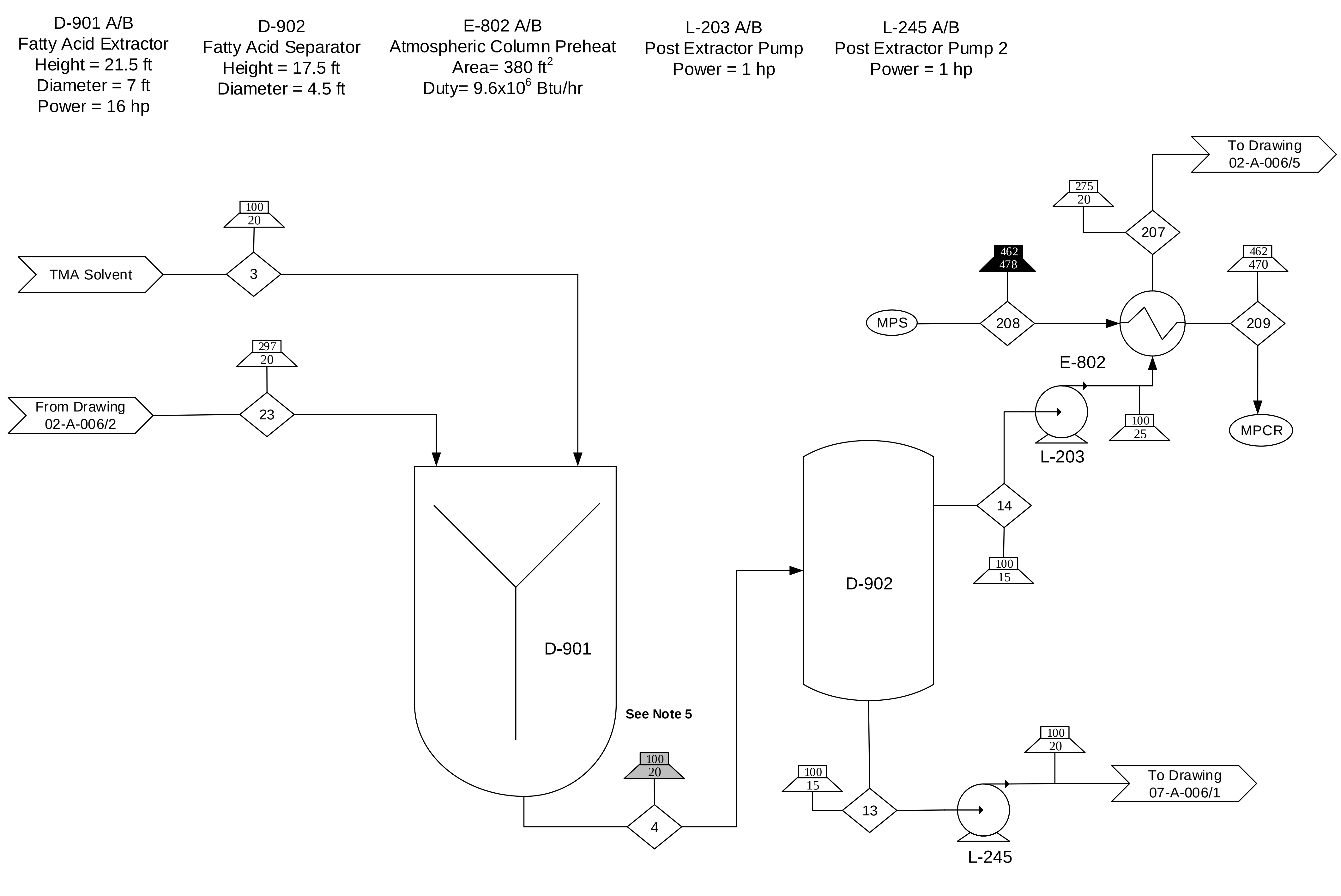
Reference Drawings:

Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
02-A-006
05-A-006
07-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-25-17	02-A-006/3	0



Component/Stream (lb/min)	3	4	13	14	23	207	208	209
C4-C50	0	0	0	0	1700	1400	0	0
TMA	340	340	340	0	0	0	0	0
Water	1400	1400	1400	0	0	0	210	210
Fatty Acids C3-C18	0	300	300	0	0	0	0	0
Organic C4-C50	0	1400	0	1400	0	0	0	0
Total	1700	3400	2000	1400	1700	1400	210	210

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
5. Stream 5 is a two phase stream composed of an aqueous and organic liquid.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
MPS Medium Pressure Steam
MPCR Medium Pressure Condensate Recycle

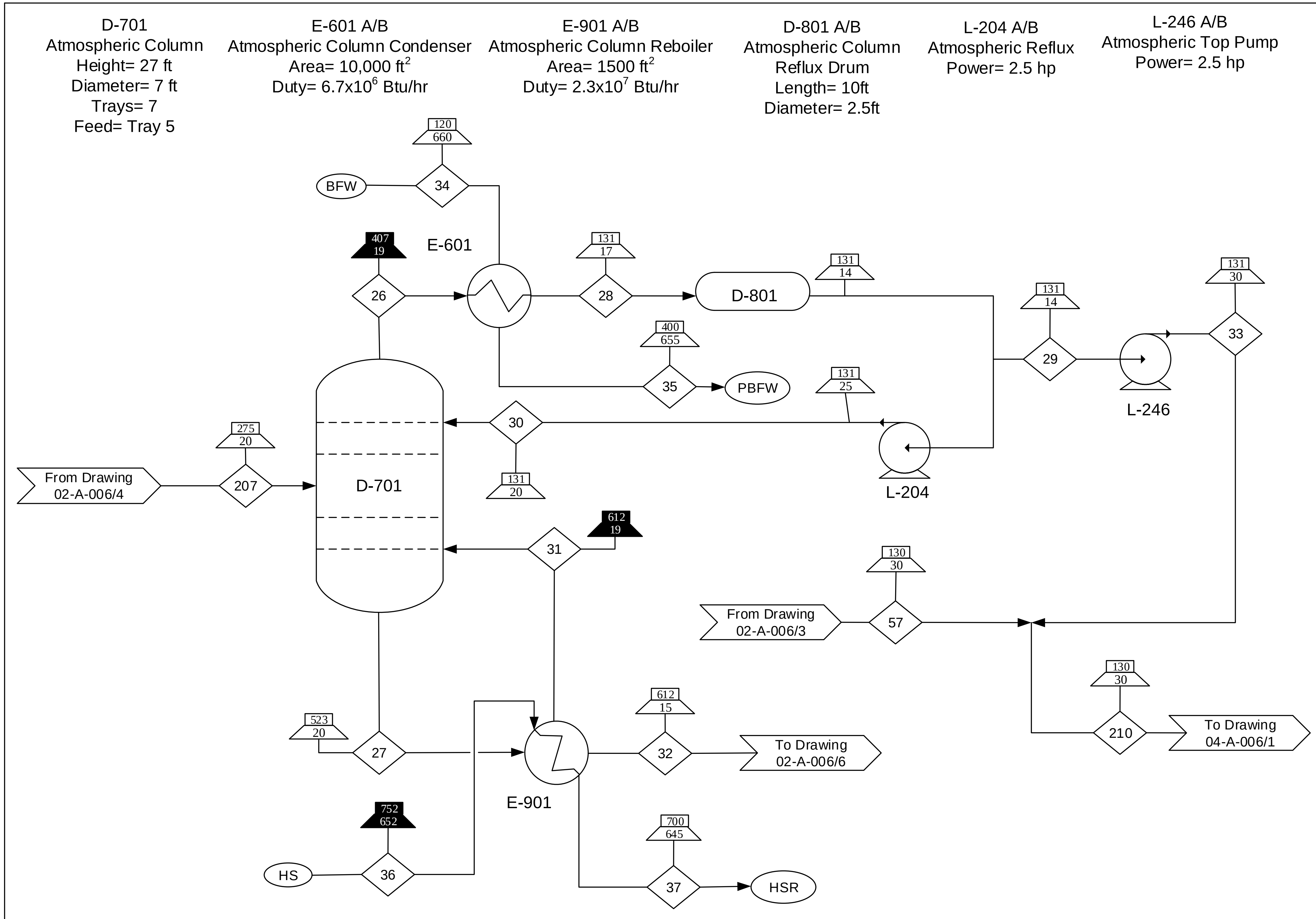
Reference Drawings:

Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
02-A-006
07-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-25-17	02-A-006/4	0



Component/Stream (lb/min)	26	27	28	29	30	31	32	33	34	35	36	37	57	207	210
C4-C12	320	0	320	300	20	0	0	300	0	0	0	0	120	0	420
C4-C50	0	2600	0	0	0	1500	0	0	0	0	0	0	0	1400	0
C13-C50	0	0	0	0	0	0	1100	0	0	0	0	0	0	0	0
Water	0	0	0	0	0	0	0	0	400	400	5100	5100	0	0	0
Total	320	2600	320	300	20	1500	1100	300	400	400	5100	5100	120	1400	420

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

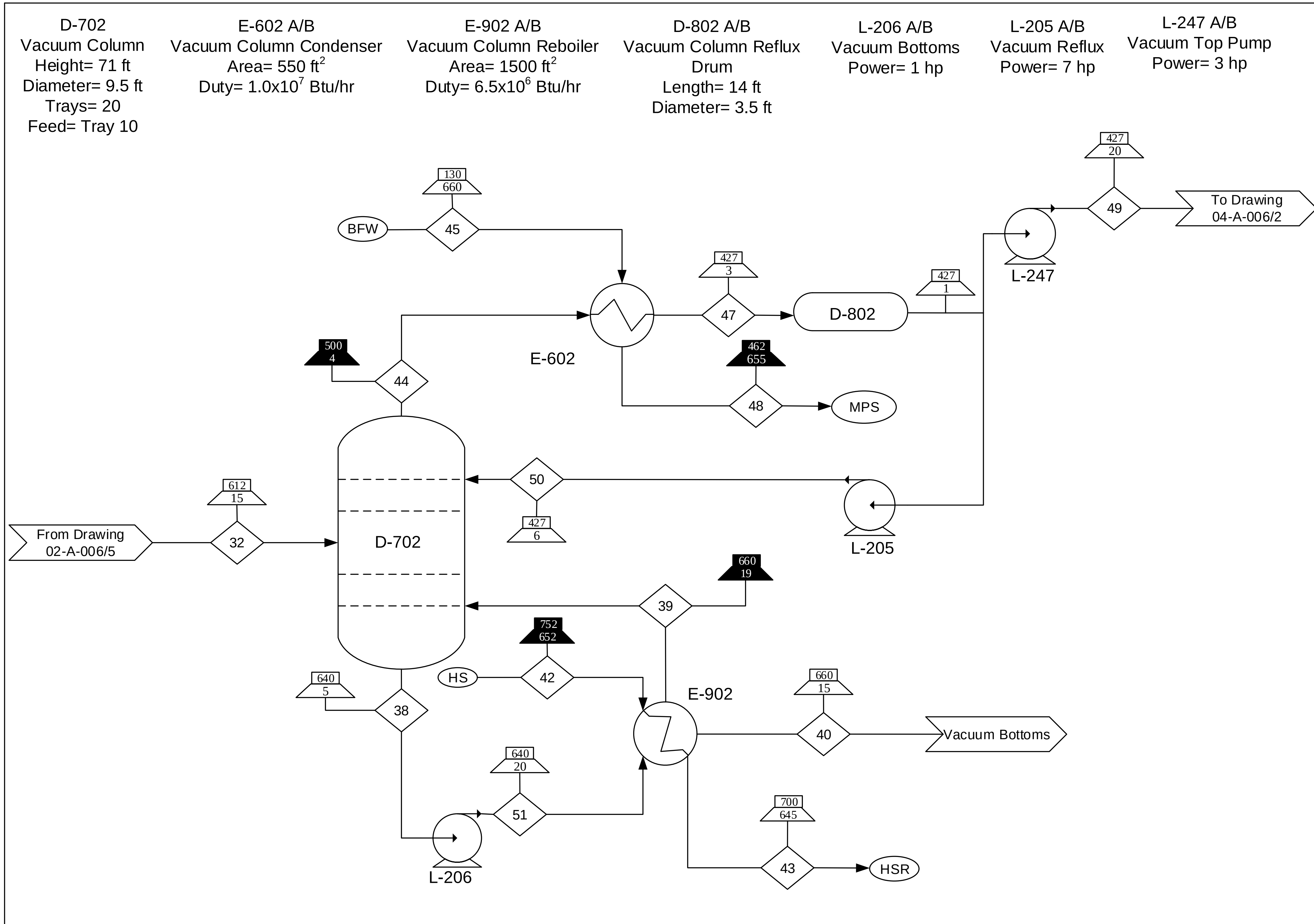
Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
HS High Pressure Steam
HSR High Pressure Steam Condensate
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

Reference Drawings:
Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
02-A-006
04-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	02-A-006/5	0



Component/Stream (lb/min)	32	38	39	40	42	43	44	45	47	48	49	50	51
C12-C50	1100	0	0	0	0	0	0	0	0	0	0	0	0
C12-C30	0	0	0	0	0	0	910	0	910	0	550	360	0
C30-C50	0	1300	710	560	0	0	0	0	0	0	0	0	1300
Water	0	0	0	0	1400	1400	0	160	0	160	0	0	0
Total	1100	1300	700	560	1400	1400	910	160	910	160	550	360	1300

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas
- HS — High Pressure Steam
- HSR — High Pressure Steam Condensate
- BFW — Boiler Feed Water
- MPS — Medium Pressure Steam

Reference Drawings:

Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
02-A-006
04-A-006

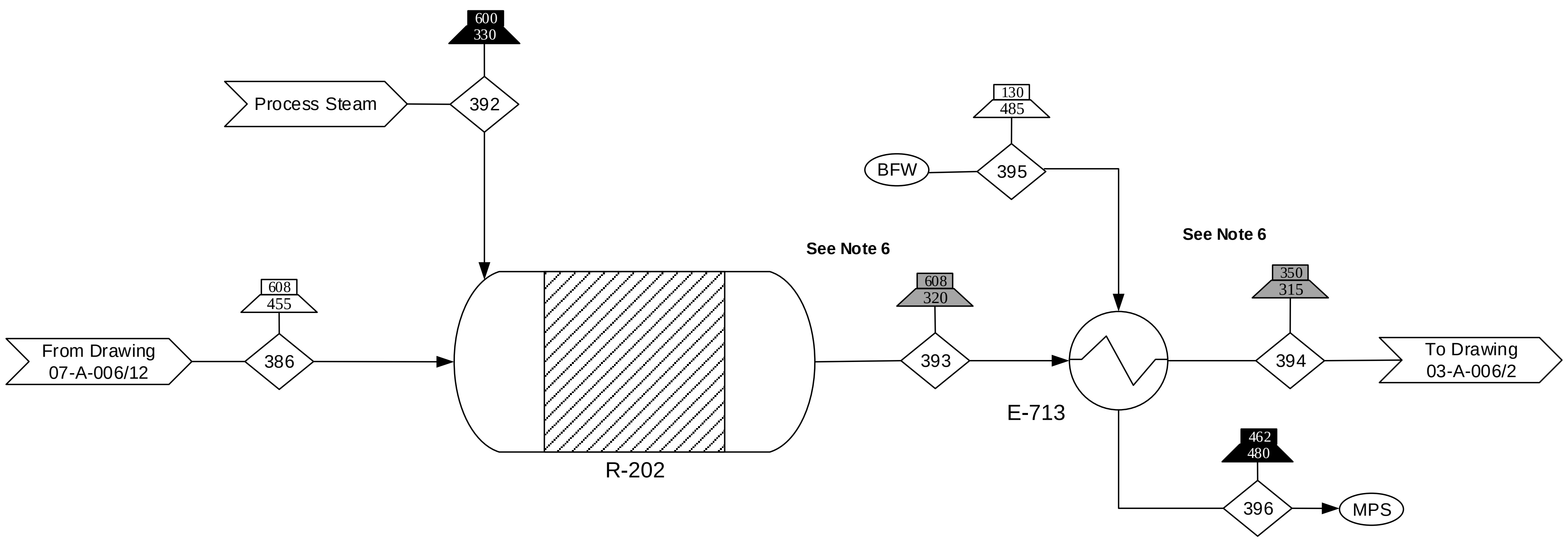
Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	02-A-006/6	0

R-202 A/B
Fatty Acid Decarboxylation Reactor
Diameter= 9 ft
Length= 37 ft
Catalyst= 2200 ft^3

E-713 A/B
Flash 4 Cooler
Area= 70 ft^2
Duty= $1.9x10^6$ Btu/hr



Component/Stream (lb/min)	386	392	393	394	395	396
Fatty Acids C12-C18	140	0	0	0	0	0
C1-C17	0	0	140	140	0	0
Water	0	4	0	0	30	30
Total	140	4	140	140	30	30

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 393 and 394 are two phase streams composed of gas and liquids.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas
- Temperature (°F) Indicator, Two Phase
- Pressure (psia) Indicator, Two Phase
- BFW Boiler Feed Water
- MPS Medium Pressure Steam

Reference Drawings:

Input/Output Diagram 00-A-004
Block Flow Diagram 00-A-005
Process Flow Diagrams 03-A-006, 07-A-006

Drawing Type
Process Flow Diagram

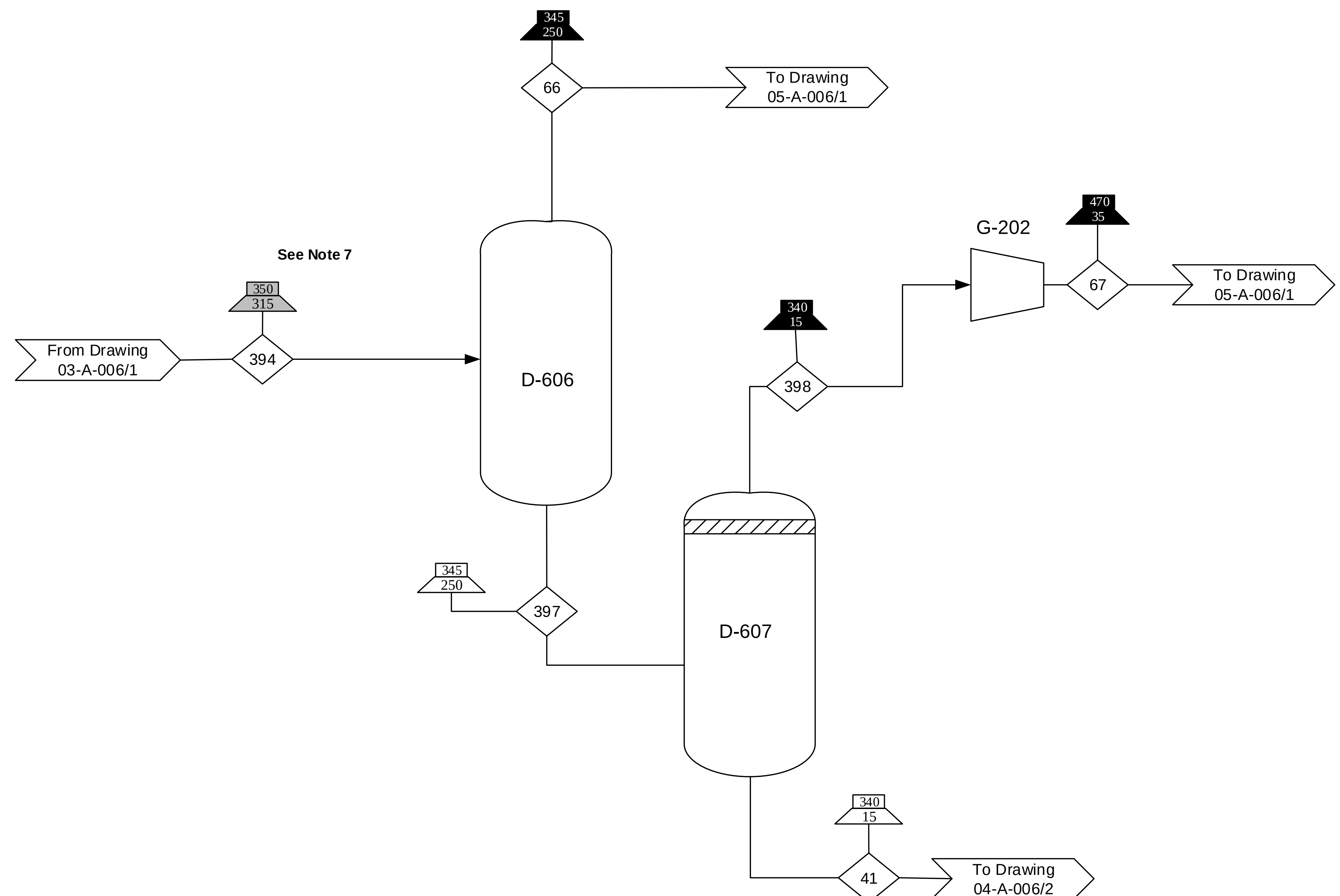
Title
Biorefinery Fatty Acid Recovery Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	03-A-006/1	0

D-606
Flash 4
Height= 9 ft
Diameter= 2.5 ft

D-607
Flash 5
Height= 9 ft
Diameter= 2.5 ft

G-202 A/B
Flash 3 Compressor
Power= 1 hp



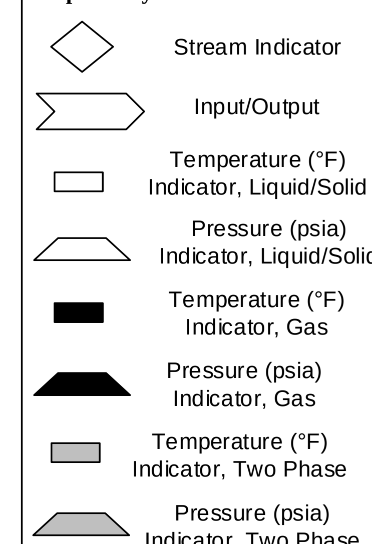
Component/Stream (lb/min)	394	66	397	398	67	41
C1-C17	140	0	110	0	0	0
C1-C7	0	30	0	1	1	0
C8-C17	0	0	0	0	0	110
Total	140	30	110	1	1	110

300

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
7. Stream 394 is composed of a liquid and gas two phase stream.

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
04-A-006
05-A-006
07-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	03-A-006/2	0

D-715
Hexane Splitter
Height= 26 ft
Diameter= 3 ft
Trays= 8
Feed 1= Stage 4
Feed 2 = Stage 3

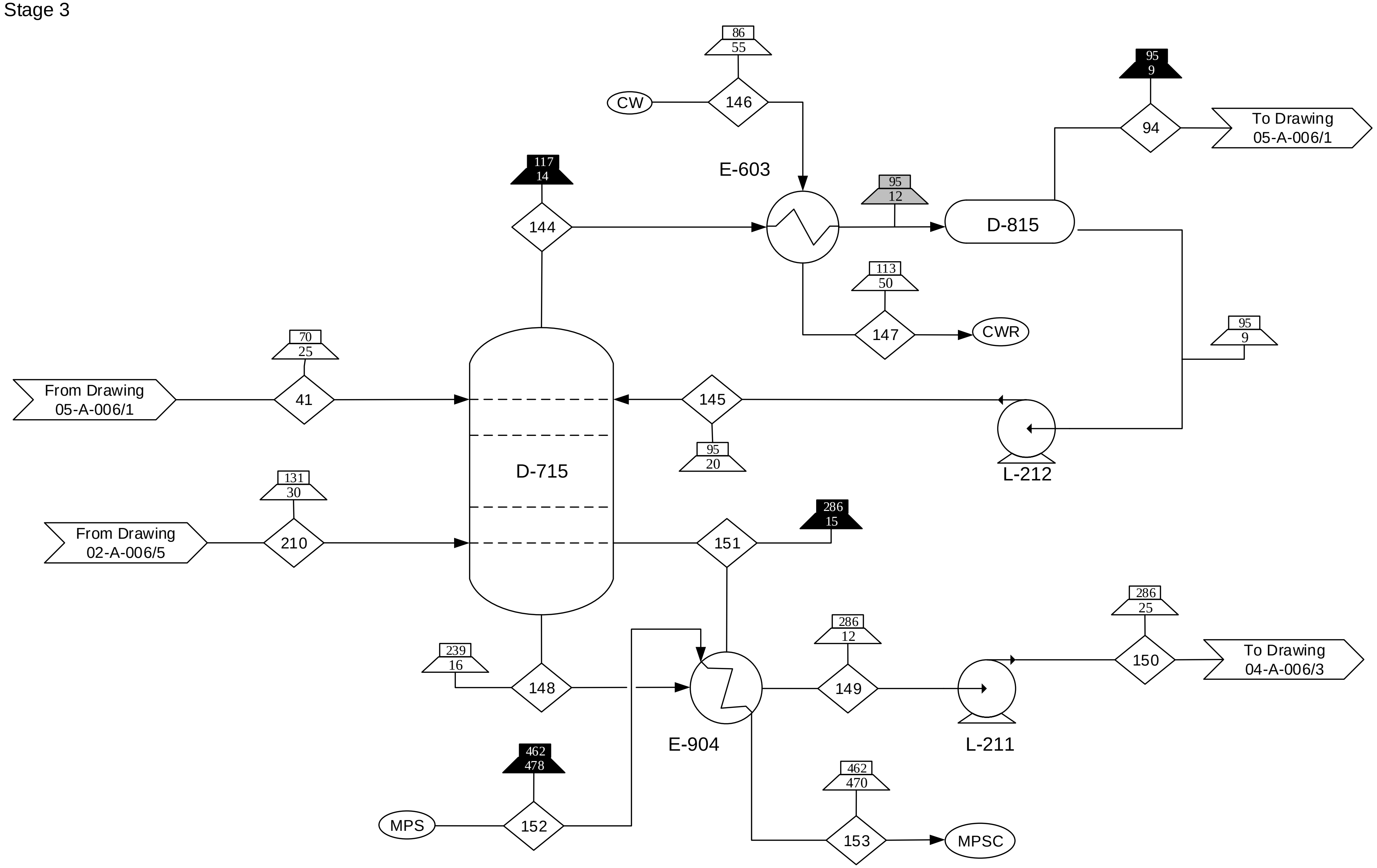
E-603 A/B
Hexane Splitter Condenser
Area= 1100 ft^2
Duty= $3.3x10^5$ Btu/hr

E-904 A/B
Hexane Splitter Reboiler
Area= 260 ft^2
Duty= $3.6x10^6$ Btu/hr

D-815 A/B
Hexane Splitter
Reflux Drum
Length= 6ft
Diameter= 1.5ft

L-211 A/B
Hexane Splitter Bottoms
Power= 1 hp

L-212 A/B
Hexane Splitter Reflux
Power= 2 hp



Component/Stream (lb/min)	41	94	144	145	146	147	148	149	150	151	152	153	210
C1-C12	30	0	0	0	0	0	0	0	0	0	0	0	420
C1-C6	0	15	40	25	0	0	0	0	0	0	0	0	0
C5-C12	0	0	0	0	0	0	660	430	430	230	0	0	0
Water	0	0	0	0	200	200	0	0	0	0	80	80	0
Total	30	30	40	25	200	200	660	430	430	230	80	80	420

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
MPS Medium Pressure Steam
MPSC Medium Pressure Steam Condensate
CW Cooling Water
CWR Cooling Water Recycle

Reference Drawings:

Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
02-A-006
04-A-006
05-A-006

Drawing Type
Process Flow Diagram

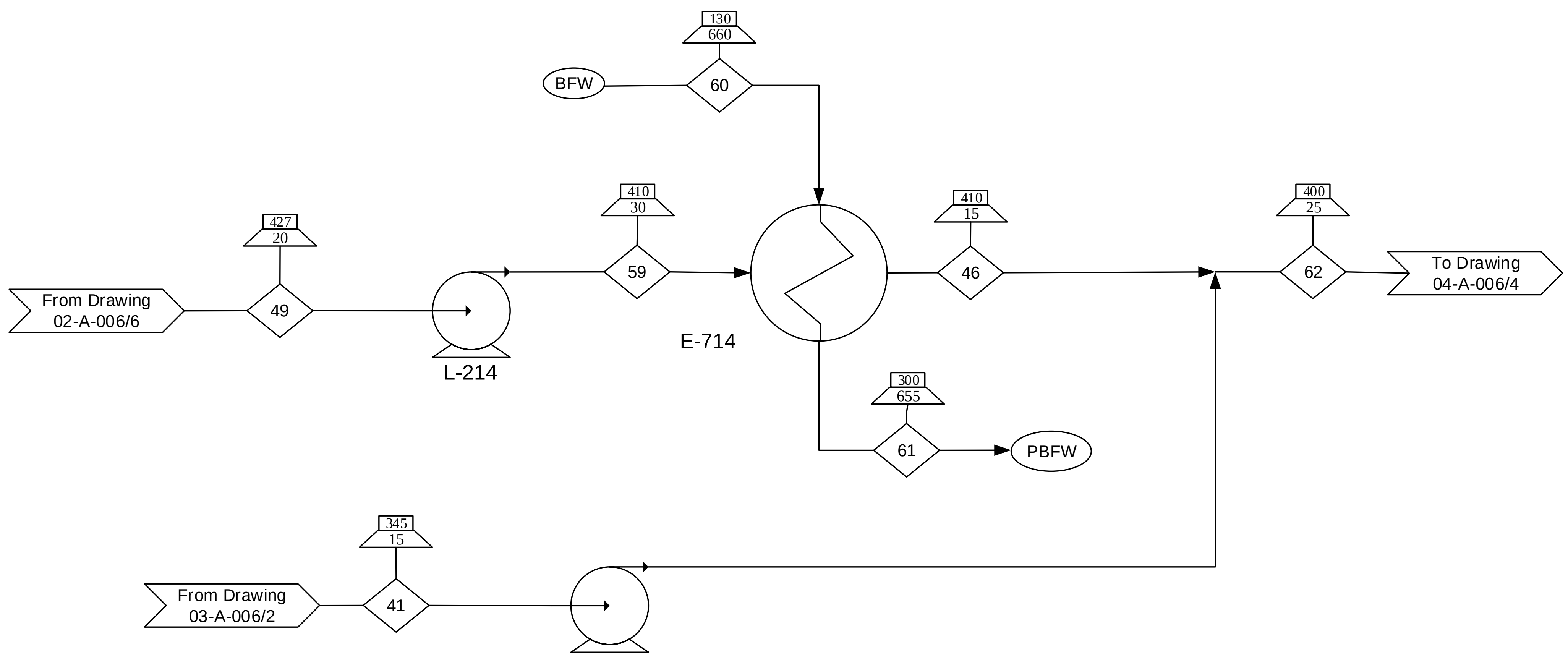
Title
Biorefinery Fatty Acid Recovery Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	04-A-006/1	0

E-714 A/B
Pre Jet Diesel Cut Cooler
Area= 33 ft^2
Duty= $4.6x10^5$ Btu/hr

L-214 A/B
Pre Jet Pump
Power = 3 hp

L-259 A/B
Pre Jet Pump 2
Power = 1 hp



Component/Stream (lb/min)	49	41	46	59	60	61	62
C12-C30	550	0	550	550	0	0	0
C11-C17	0	110	0	0	0	0	0
C11-C30	0	0	0	0	0	0	660
Water	0	0	0	0	7	7	0
Total	550	110	550	550	7	7	660

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas
- BFW Boiler Feed Water
- PBFW Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
02-A-006
03-A-006
04-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	04-A-006/2	0

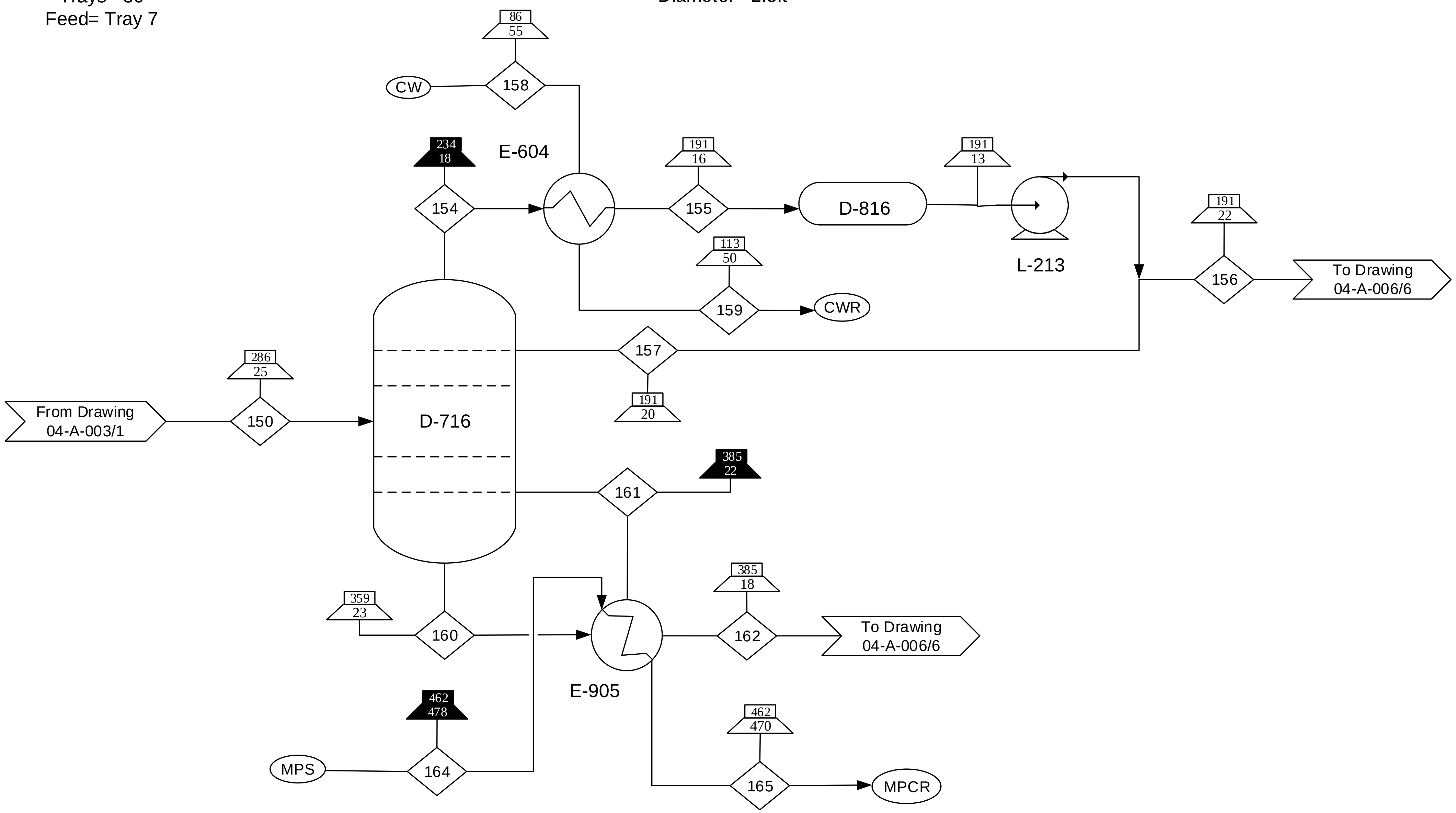
D-716
Naphtha-Jet Cut
Height= 91 ft
Diameter= 5 ft
Trays= 30
Feed= Tray 7

E-604 A/B
Naphtha Jet Condenser
Area= 500 ft^2
Duty= 2.8×10^6 Btu/hr

E-905 A/B
Naphtha Jet Cut Reboiler
Area= 460 ft^2
Duty= 3.9×10^6 Btu/hr

D-816 A/B
Naphtha-Jet Cut
Reflux Drum
Length= 10ft
Diameter= 2.5ft

L-213 A/B
Naphtha Jet Reflux
Power= 7 hp



Component/Stream (lb/min)	150	154	155	156	157	158	159	160	161	162	164	165
C5-C12	430	0	0	0	0	0	0	0	0	0	0	0
C7-C9	0	230	230	100	130	0	0	0	0	0	0	0
C9-C12	0	0	0	0	0	0	0	350	20	330	0	0
Water	0	0	0	0	0	1700	1700	0	0	0	85	85
Total	430	230	230	100	130	1700	1700	350	20	330	85	85

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
MPS Medium Pressure Steam
MPCR Medium Pressure Condensate Recycle
CW Cooling Water
CWR Cooling Water Recycle

Reference Drawings:

Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
04-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	04-A-006/3	0

D-717
Jet Diesel Cut Column
Height= 81 ft
Diameter= 10 ft
Trays= 25
Feed= Tray 13

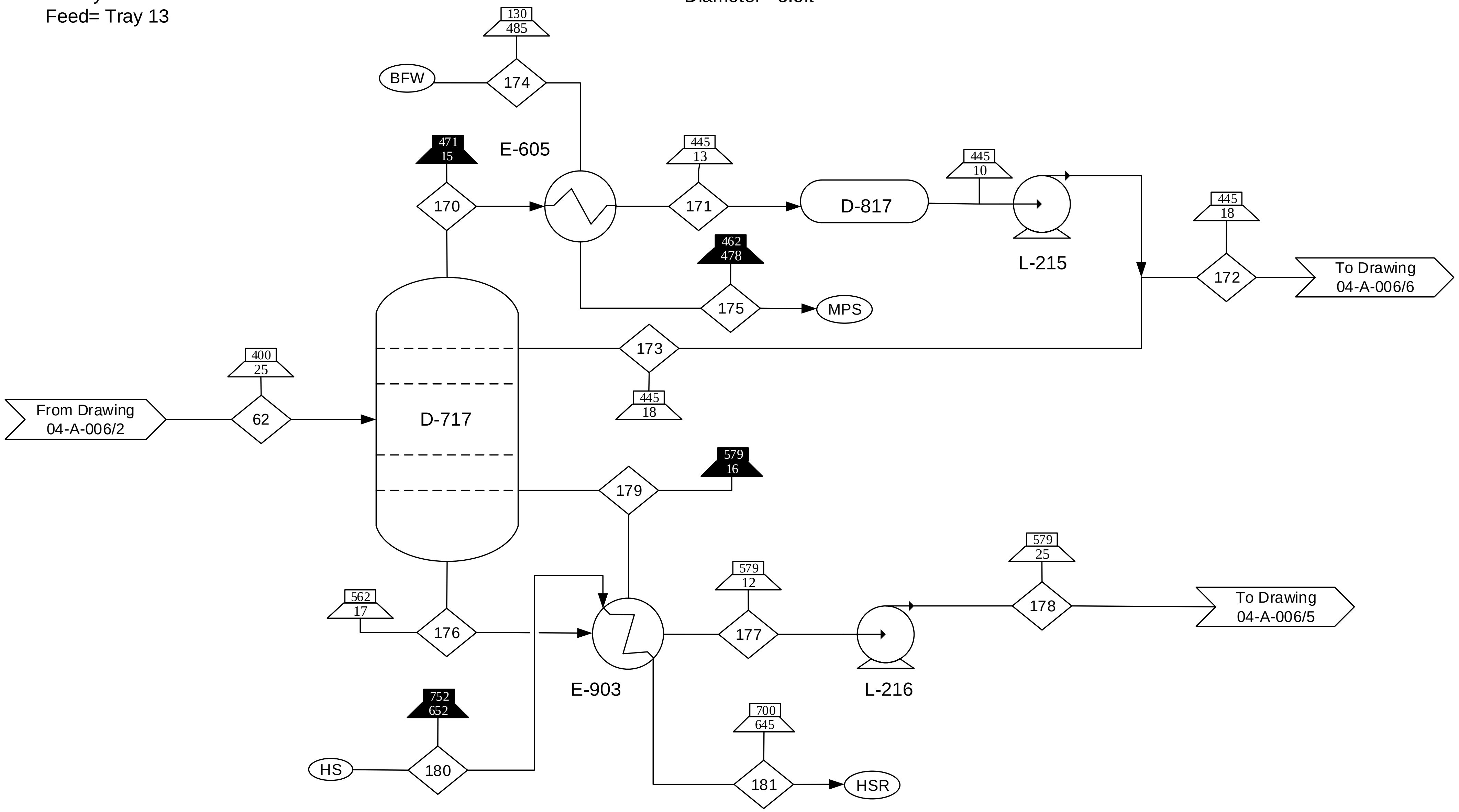
E-605 A/B
Jet Diesel Cut Condenser
Area= 560 ft^2
Duty= $7.2x10^6$ Btu/hr

E-903 A/B
Jet Diesel Cut Reboiler
Area= 1300 ft^2
Duty= $1.2x10^7$ Btu/hr

D-304 A/B
Jet-Diesel Cut
Reflux Drum
Length= 14ft
Diameter= 3.5ft

L-215 A/B
Jet Diesel Cut Reflux
Power= 6 hp

L-216 A/B
Jet Diesel Cut Bottoms
Power= 1 hp



Component/Stream (lb/min)	62	170	171	172	173	174	175	176	177	178	179	180	181
C11-C30	660	0	0	0	0	0	0	0	0	0	0	0	0
C11-C30	0	760	760	140	620	0	0	0	0	0	0	0	0
C16-C30	0	0	0	0	0	0	0	1500	530	530	970	0	0
Water	0	0	0	0	0	110	110	0	0	0	0	2800	2800
Total	660	760	760	140	620	110	110	1500	530	530	970	2800	2800

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas
- HS: High Pressure Steam
- HSR: High Pressure Steam Recycle
- BFW: Boiler Feed Water
- MPS: Medium Pressure Steam

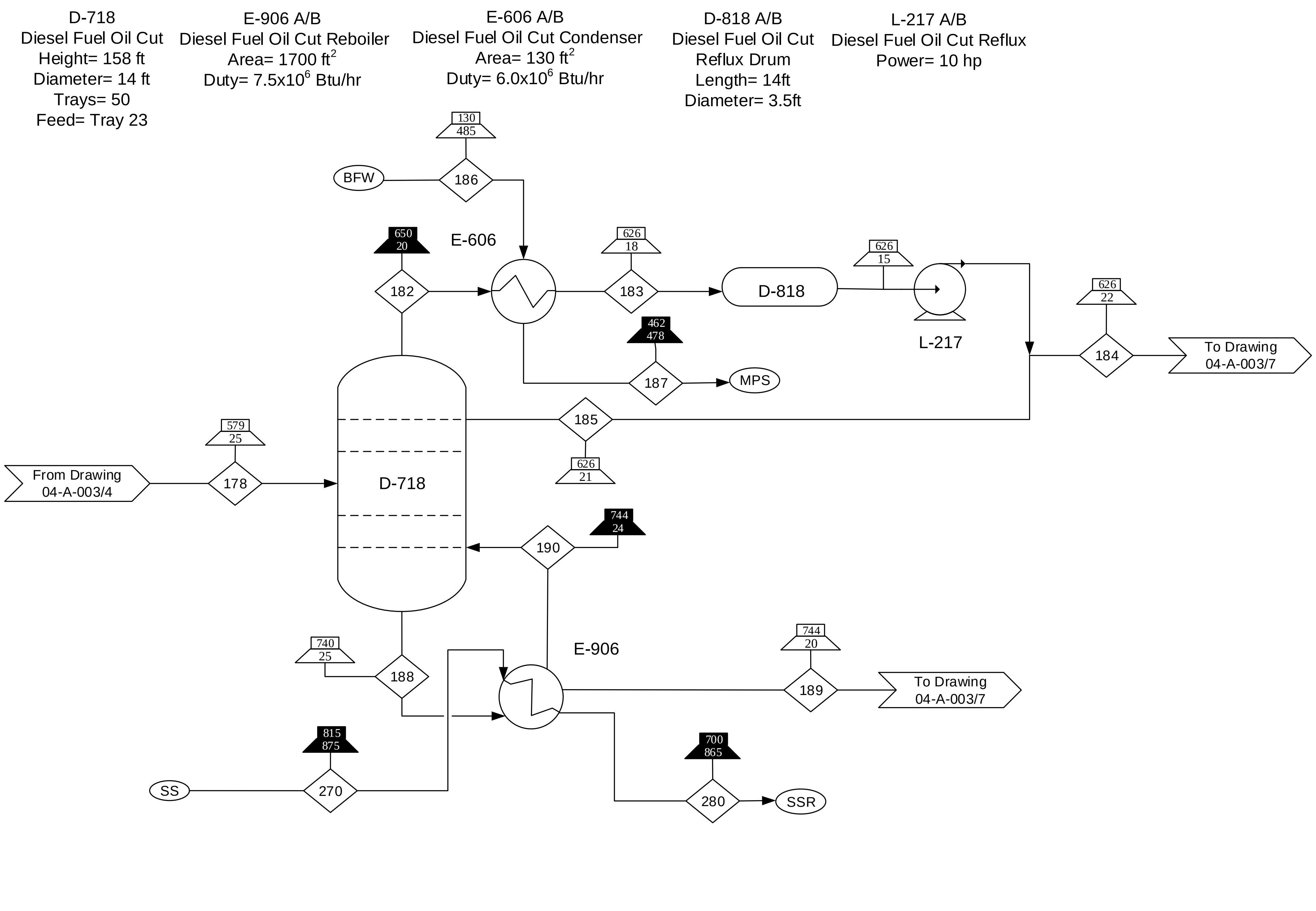
Reference Drawings:

Input/Output Diagram 00-A-004
Block Flow Diagram 00-A-005
Process Flow Diagrams 04-A-006

Drawing Type: Process Flow Diagram

Title: Biorefinery Fatty Acid Recovery Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	04-A-006/4	0



Component/Stream (lb/min)	178	182	183	184	185	186	187	188	189	190	270	280
C16-C30	530	0	0	0	0	0	0	0	0	0	0	0
C16-C21	0	760	760	520	240	0	0	0	0	0	0	0
C22-C30	0	0	0	0	0	0	0	1300	5	1300	0	0
Water	0	0	0	0	0	95	95	0	0	0	6000	6000
Total	530	760	760	520	240	95	95	1300	5	1300	6000	6000

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
MPS Medium Pressure Steam
BFW Boiler Feed Water
SS Superheated Steam
SSR Superheated Steam Recycle

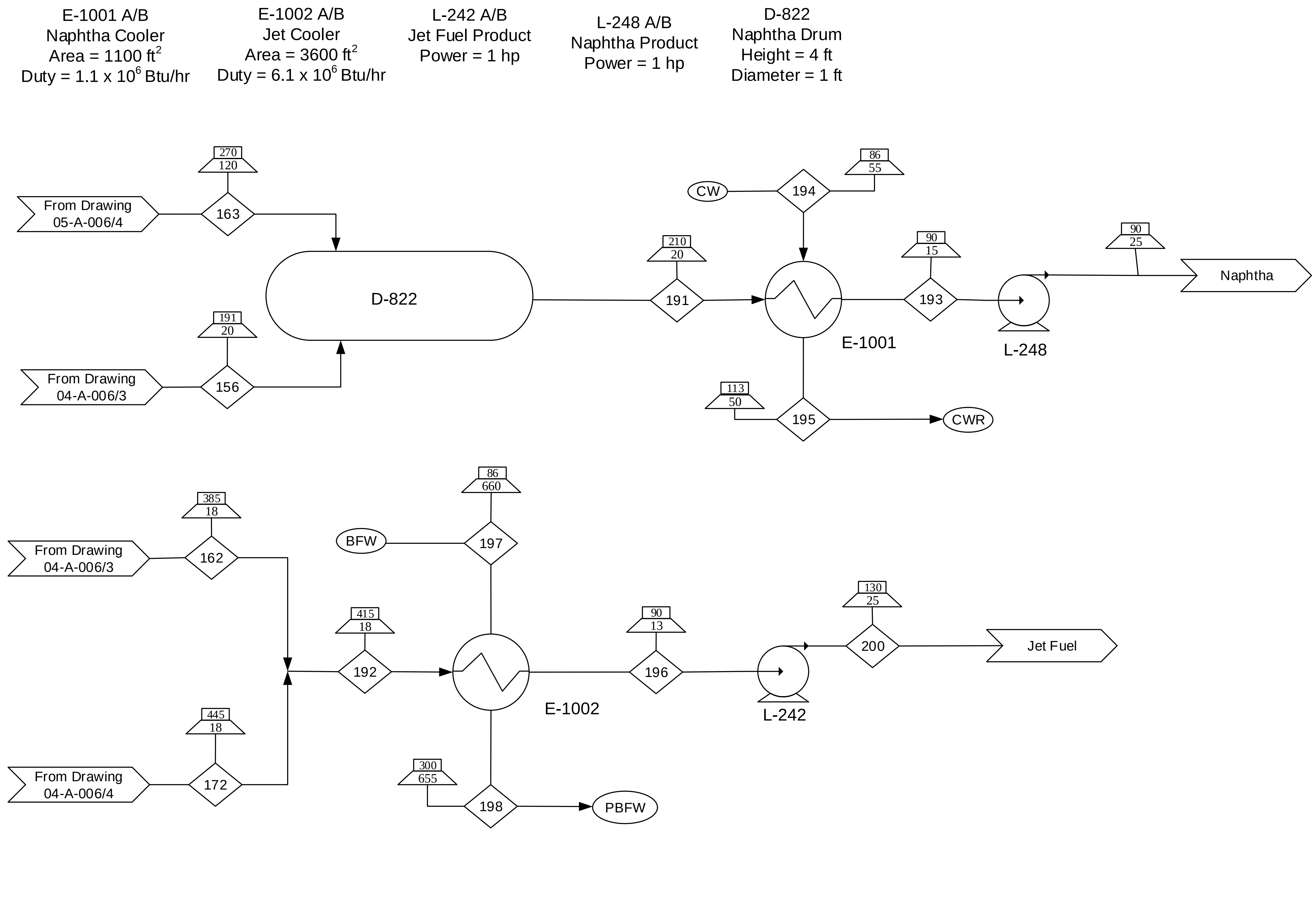
Reference Drawings:

Input/Output Diagram 00-A-004
Block Flow Diagram 00-A-005
Process Flow Diagrams 04-A-006

Drawing Type: Process Flow Diagram

Title: Biorefinery Fatty Acid Recovery Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	04-A-006/5	0

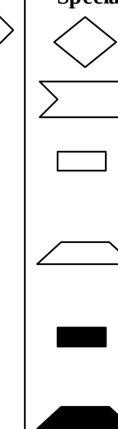


Component/Stream (lb/min)	156	162	163	172	191	192	193	194	195	196	197	198	200
Naphtha Product	100	0	85	0	190	0	190	0	0	0	0	0	0
Jet Fuel Product	0	330	0	140	0	460	0	0	0	460	0	0	460
Water	0	0	0	0	0	0	0	670	670	0	3800	3800	0
Total	100	330	85	140	190	460	190	670	670	460	3800	3800	460

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature



Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
CW Cooling Water
CWR Cooling Water Recycle
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

Reference Drawings:

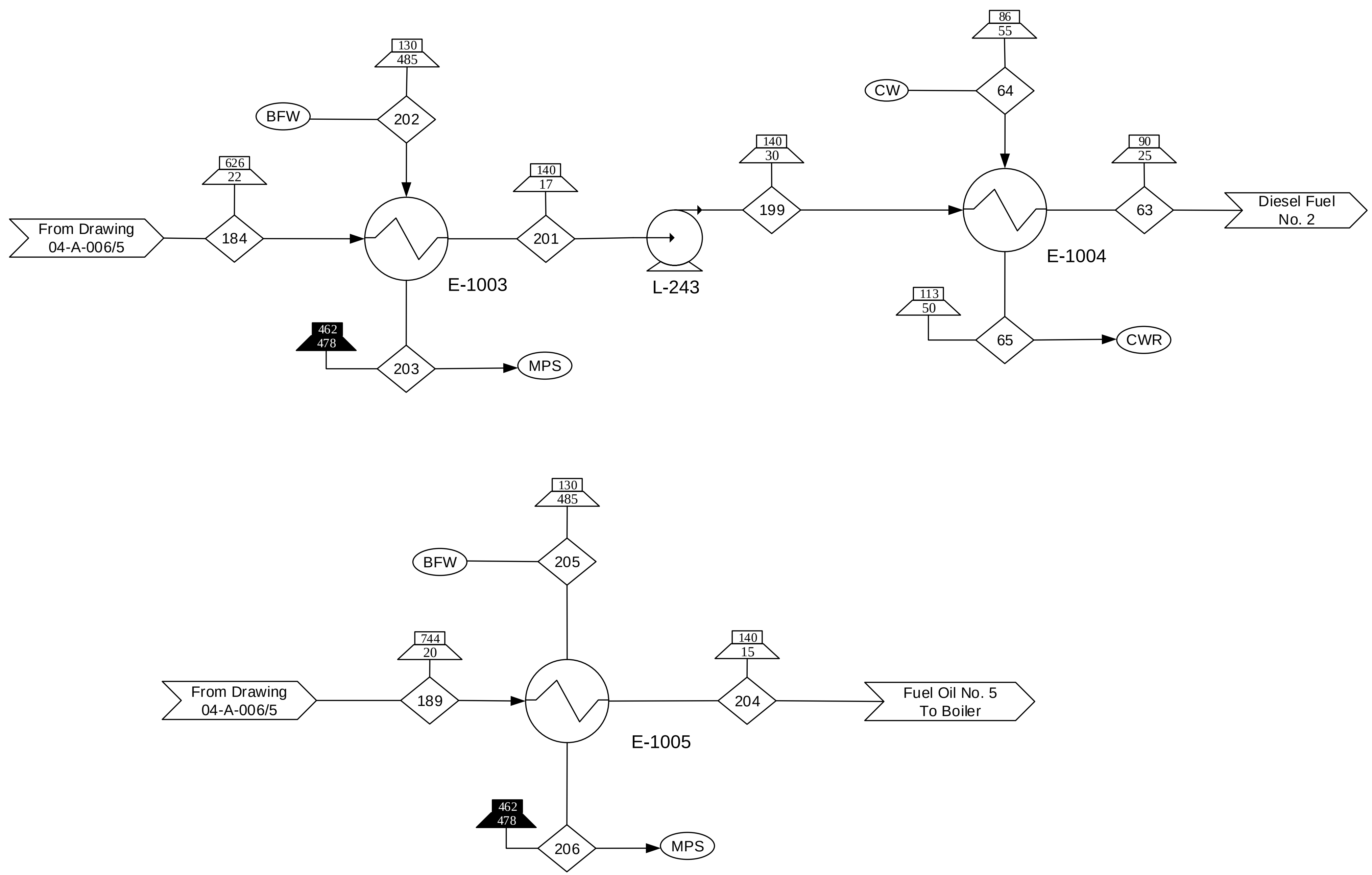
Input/Output Diagram 00-A-004
Block Flow Diagram 00-A-005
Process Flow Diagrams 04-A-006 05-A-006

Drawing Type: Process Flow Diagram

Title: Biorefinery Fatty Acid Recovery Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	04-A-006/6	0

E-1003 A/B	E-1004 A/B	E-1005 A/B	L-243 A/B
Diesel Cooler 1	Diesel Cooler 2	Fuel Oil Cooler	Diesel Product
Area = 1500 ft^2	Area = 1600 ft^2	Area = 30 ft^2	Power = 1 hp
Duty = 1.2×10^7 Btu/hr	Duty = 9.6×10^5 Btu/hr	Duty = 1.4×10^5 Btu/hr	



Component/Stream (lb/min)	63	64	65	184	189	201	202	203	204	205	206	199
Diesel Fuel No. 2 Product	520	0	0	520	0	520	0	0	0	0	0	520
Fuel Oil No. 5 Product	0	0	0	0	5	0	0	0	5	0	0	0
Water	0	600	600	0	0	0	190	190	0	90	90	0
Total	520	600	600	520	5	520	190	190	5	90	90	520

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°F) Indicator, Liquid/Solid

Pressure (psia) Indicator, Liquid/Solid

Temperature (°F) Indicator, Gas

Pressure (psia) Indicator, Gas

MPS Medium Pressure Steam

BFW Boiler Feed Water

CW Cooling Water

CWR Cooling Water Recycle

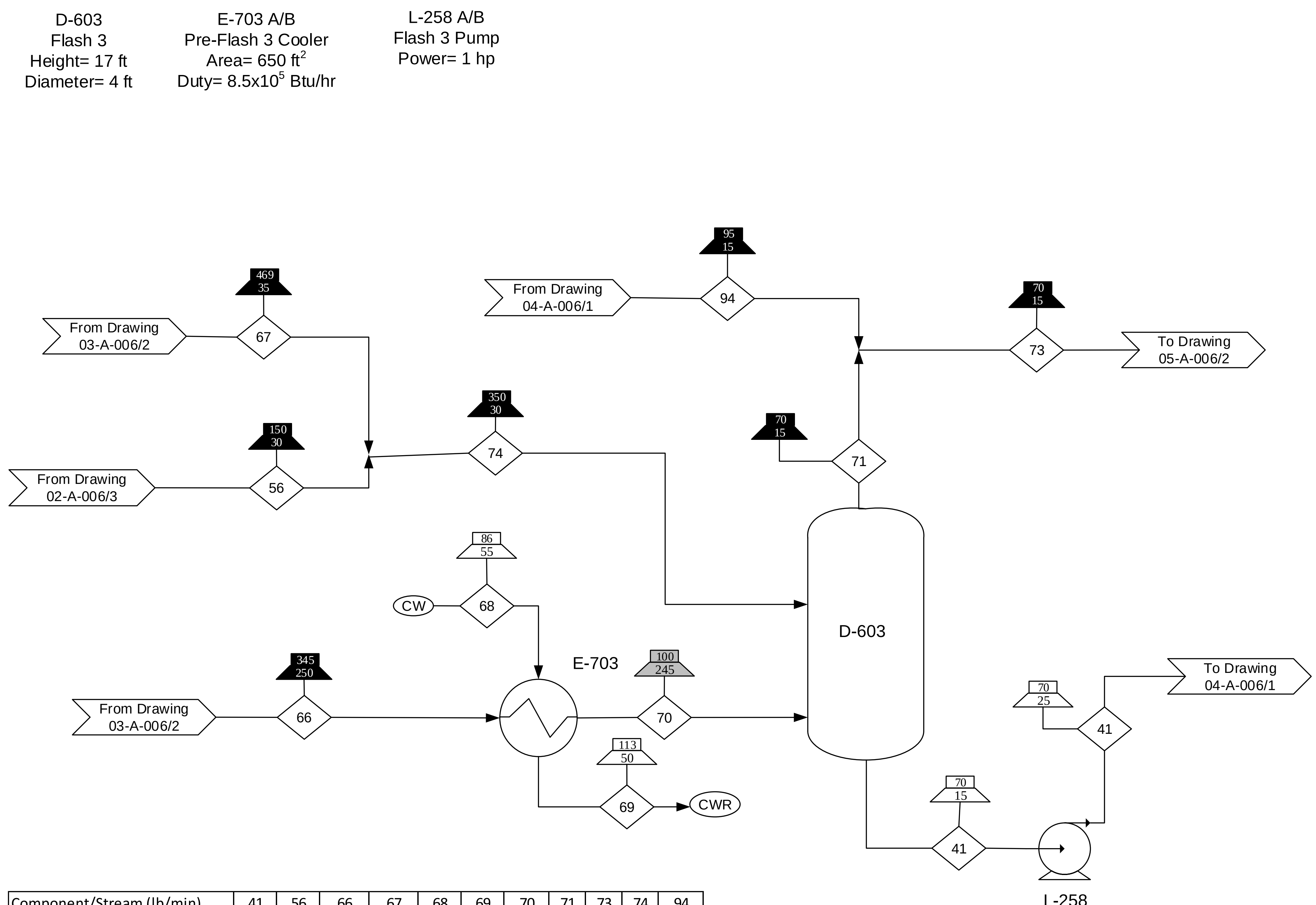
Reference Drawings:

Input/Output Diagram 00-A-004
Block Flow Diagram 00-A-005
Process Flow Diagrams 04-A-006 05-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	04-A-006/7	0



Component/Stream (lb/min)	41	56	66	67	68	69	70	71	73	74	94
C1-C5	0	0	0	0	0	0	0	380	400	0	15
C5-C7	30	0	0	0	0	0	0	0	0	0	0
C1-C7	0	380	30	1	0	0	30	0	0	380	0
C1-C6	0	0	0	0	0	0	0	0	0	0	0
C6-C7	0	0	0	0	0	0	0	0	0	0	0
Water	0	0	0	0	520	520	0	0	0	0	0
Total	30	380	30	1	520	520	30	380	400	380	15

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
CW Cooling Water
CWR Cooling Water Recycle

Reference Drawings:

Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
02-A-006
03-A-006
04-A-006
05-A-006

Drawing Type
Process Flow Diagram

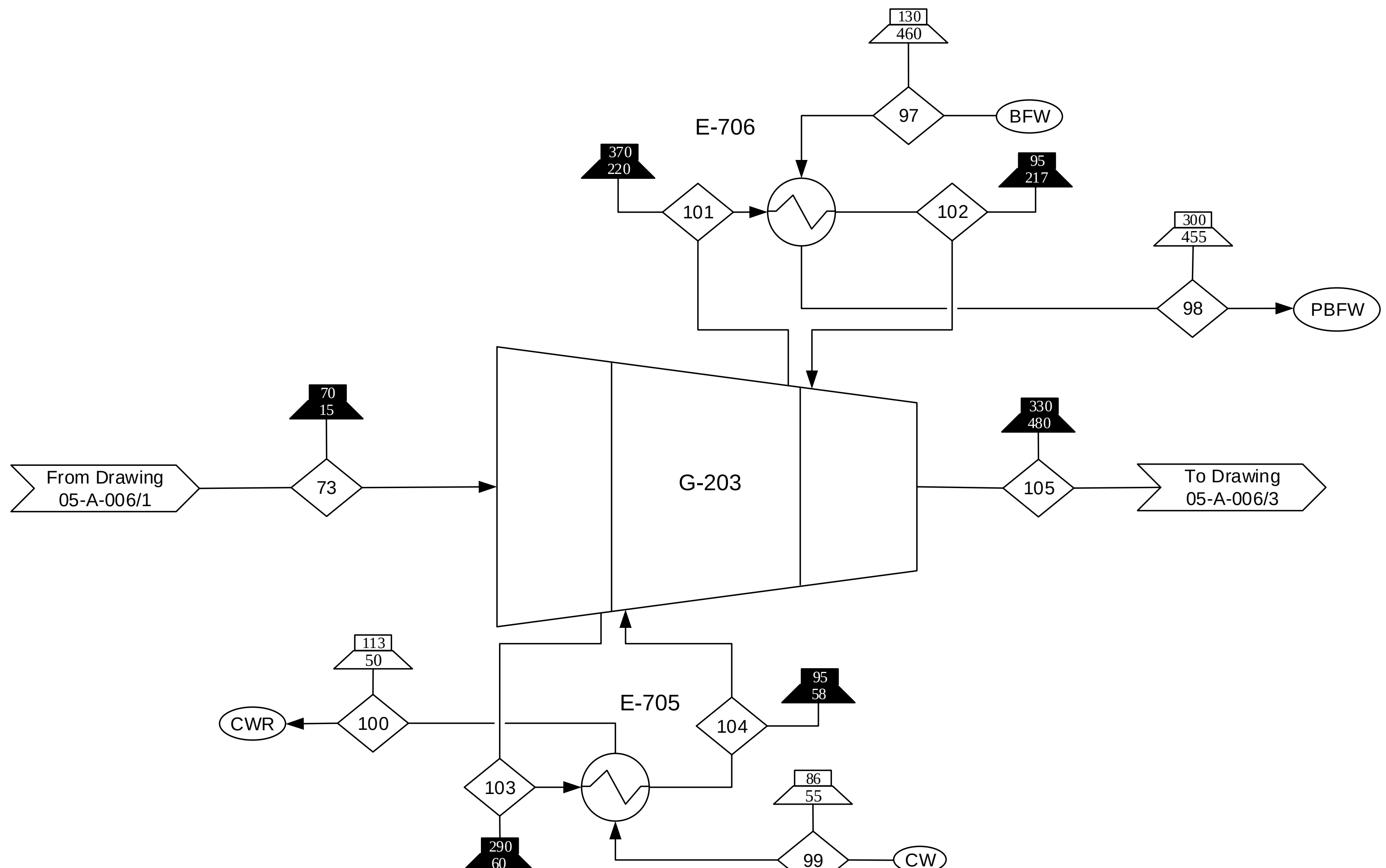
Title
Biorefinery Fatty Acid Recovery Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	05-A-006/1	0

G-203
Light End Compressor
3 Stages
Stage 1 Power= 700 hp
Stage 2 Power= 700 hp
Stage 3 Power= 700 hp

E-705 A/B
Interstage Cooler 1
Area= 390 ft^2
Duty= 1.8×10^6 Btu/hr

E-706 A/B
Interstage Cooler 2
Area= 430 ft^2
Duty= 2.2×10^6 Btu/hr



Component/Stream (lb/min)	73	97	98	99	100	101	102	103	104	105
C1-C5	400	0	0	0	0	400	400	400	400	400
Water	0	1300	1300	1100	1100	0	0	0	0	0
Total	400	1300	1300	1100	1100	400	400	400	400	400

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
CW Cooling Water
CWR Cooling Water Recycle
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

Reference Drawings:

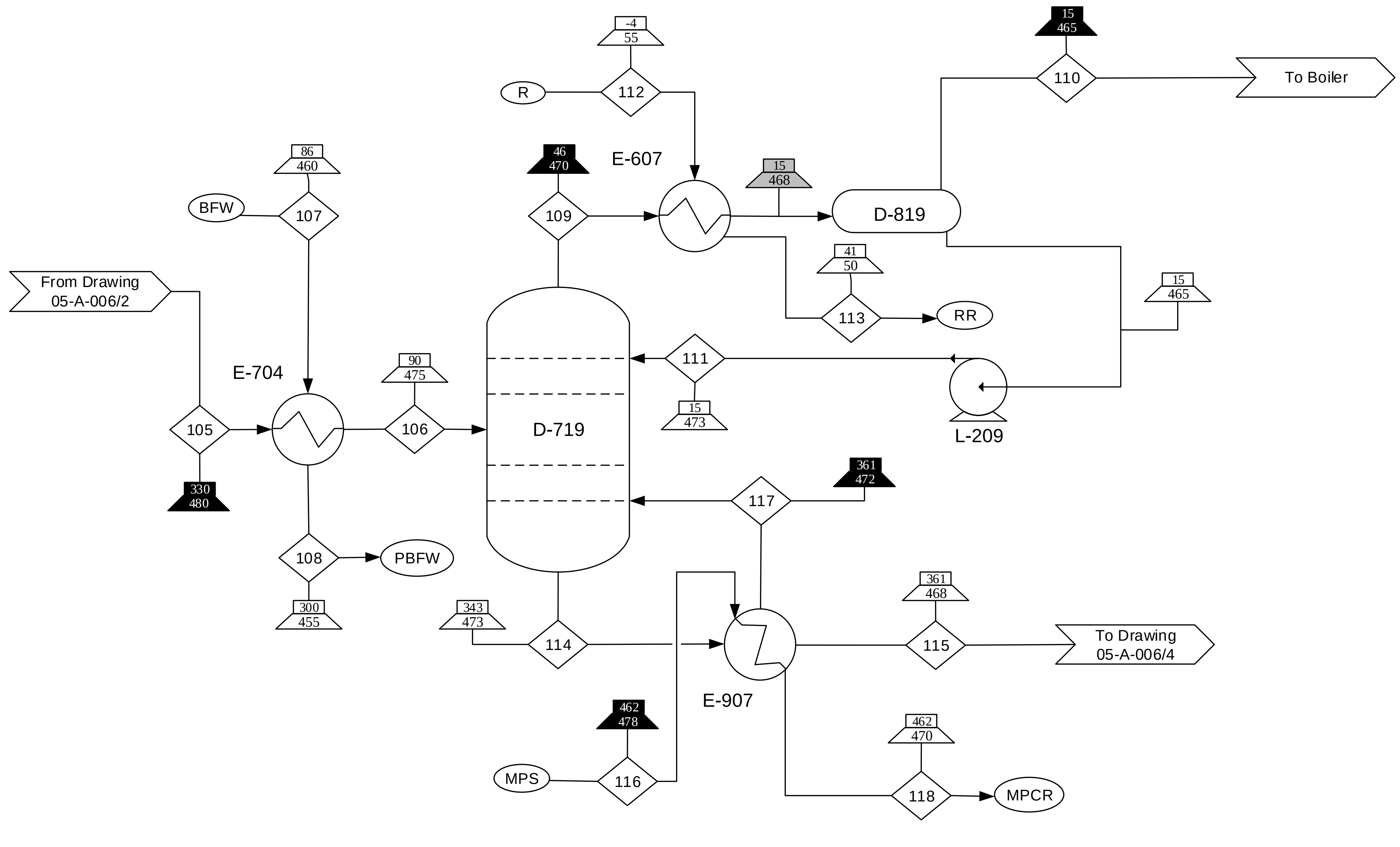
Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
05-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	05-A-006/2	0

D-719	E-704 A/B	E-607 A/B	E-907 A/B	D-819 A/B	L-209 A/B
Syngas Column	Syngas Cooler	Syngas Condenser	Syngas Reboiler	Syngas Column Reflux Drum	Syngas Column Reflux
Height= 120 ft	Area= 8700 ft^2	Area= 2500 ft^2	Area= 150 ft^2	Length= 12ft	Power= 7 hp
Diameter= 7.5 ft	Duty= $8.2x10^6$ Btu/hr	Duty= $1.3x10^6$ Btu/hr	Duty= $2.5x10^6$ Btu/hr	Diameter= 3ft	
Trays= 40					
Feed= Tray 15					



Component/Stream (lb/min)	105	106	107	108	109	110	111	112	113	114	115	116	117	118
C1-C5	400	400	0	0	0	0	0	0	0	0	0	0	0	0
C1-C3	0	0	0	0	380	270	110	0	0	0	0	0	0	0
C4-C5	0	0	0	0	0	0	0	0	0	450	130	0	320	0
Water	0	0	5100	5100	0	0	0	800	800	0	0	55	0	55
Total	400	400	5100	5100	380	270	110	800	800	450	130	55	320	55

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas
- Temperature (°F) Indicator, Two Phase
- Pressure (psia) Indicator, Two Phase
- MPS: Medium Pressure Steam
- MPCR: Medium Pressure Condensate Recycle
- R: Refrigerant
- RR: Refrigerant Return
- BFW: Boiler Feed Water
- PBFW: Preheated Boiler Feed Water

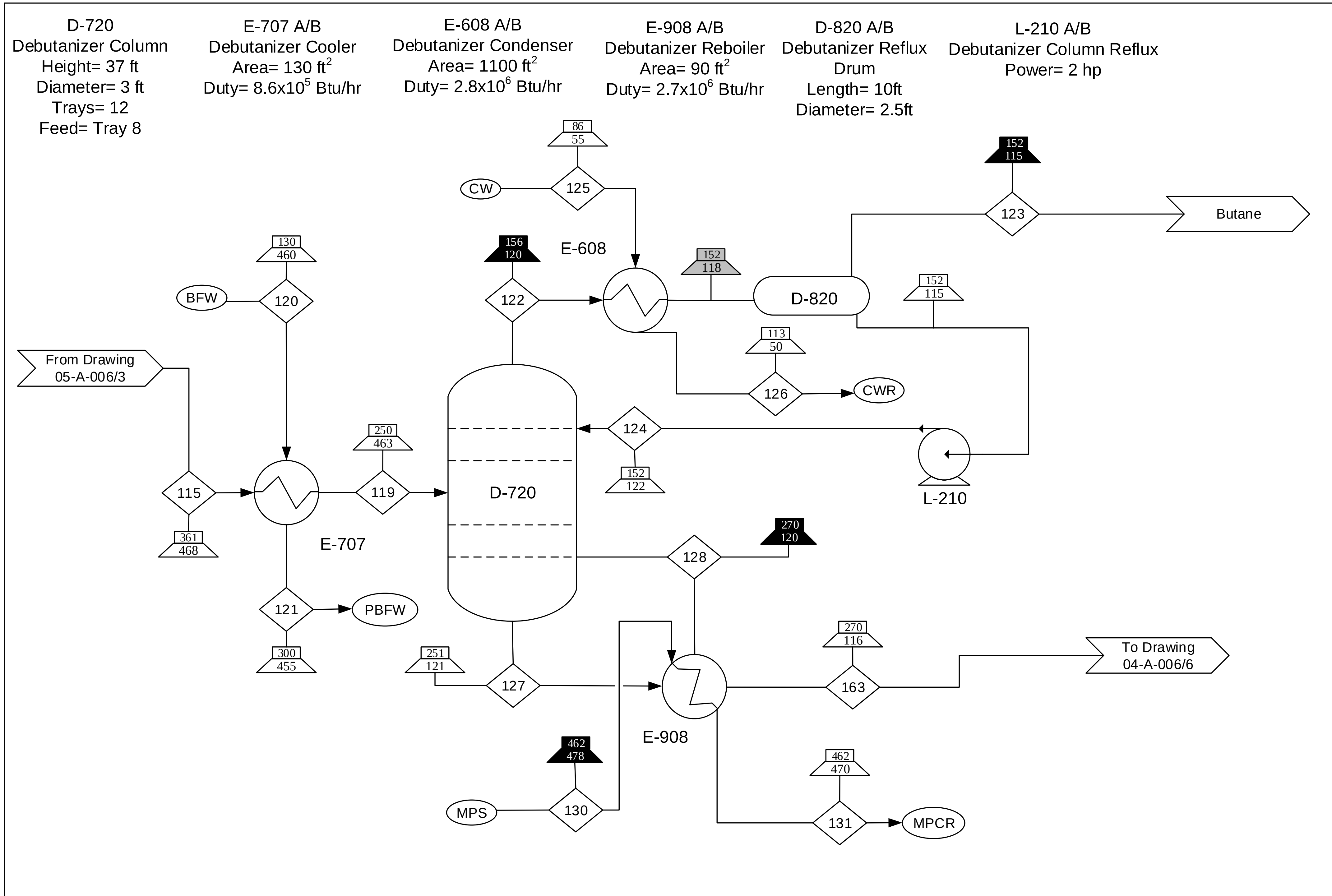
Reference Drawings:

Input/Output Diagram 00-A-004
Block Flow Diagram 00-A-005
Process Flow Diagrams 05-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	05-A-006/3	0



Component/Stream (lb/min)	115	119	120	121	122	123	124	125	126	127	128	130	131	163
C4-C6	130	130	0	0	0	0	0	0	0	0	0	0	0	0
Butane	0	0	0	0	280	42	240	0	0	0	0	0	0	0
C5-C6	0	0	0	0	0	0	0	0	0	350	260	0	0	85
Water	0	0	530	530	0	0	0	1800	1800	0	0	60	60	0
Total	130	130	530	530	280	42	240	1800	1800	350	260	60	60	85

Notes

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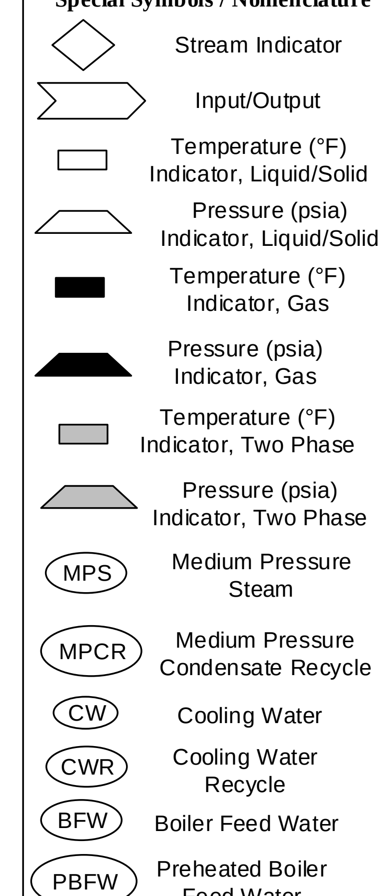
5. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

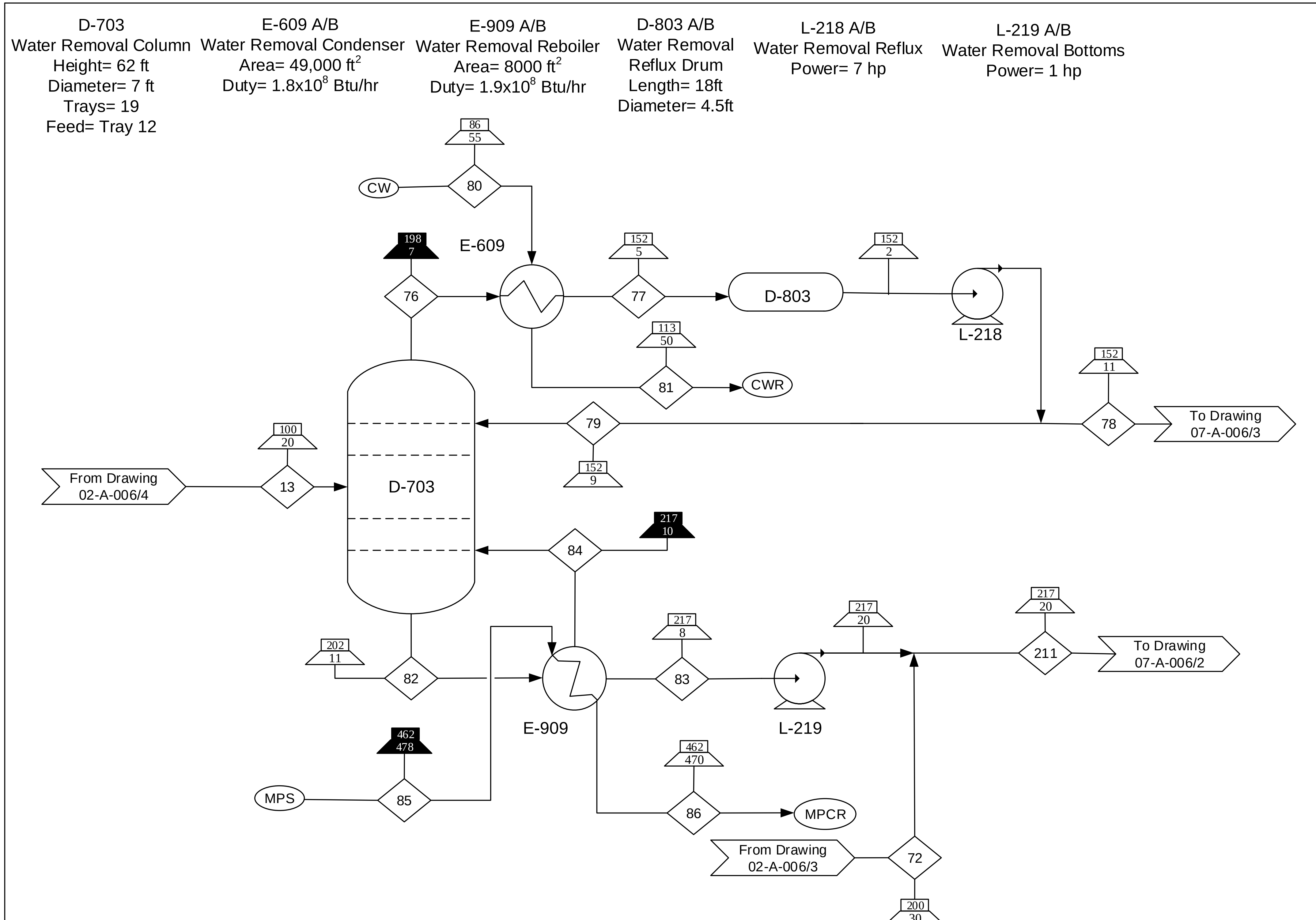


Reference Drawings:
Process Flow Diagrams
04-A-006
05-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	05-A-006/4	0



Component/Stream (lb/min)	13	72	76	77	78	79	80	81	82	83	84	85	86	211
Fatty Acids C1-C18	300	0	0	0	0	0	0	0	800	280	520	0	0	290
Fatty Acids C2-C3	0	10	0	0	0	0	0	0	0	0	0	0	0	10
TMA	340	0	610	610	340	270	0	0	0	0	0	0	0	0
Water	1400	0	2300	2300	1300	1000	110000	110000	190	68	120	4200	4200	68
Total	2000	10	2900	2900	1600	1300	110000	110000	990	350	640	4200	4200	360

Notes

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3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
MPS — Medium Pressure Steam
MPCR — Medium Pressure Condensate Recycle
CW — Cooling Water
CWR — Cooling Water Recycle

Reference Drawings:

Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
02-A-006
07-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-26-17	07-A-006/1	0

D-704
C2-C4 FA Split Column
Height= 62 ft
Diameter= 5 ft
Trays= 20
Feed= Tray 16

E-610 A/B
C2-C4 FA Split Condenser
Area= 15,000 ft^2
Duty= 1.9×10^7 Btu/hr

E-910 A/B
C2-C4 FA Split Reboiler
Area= 1400 ft^2
Duty= 2.0×10^7 Btu/hr

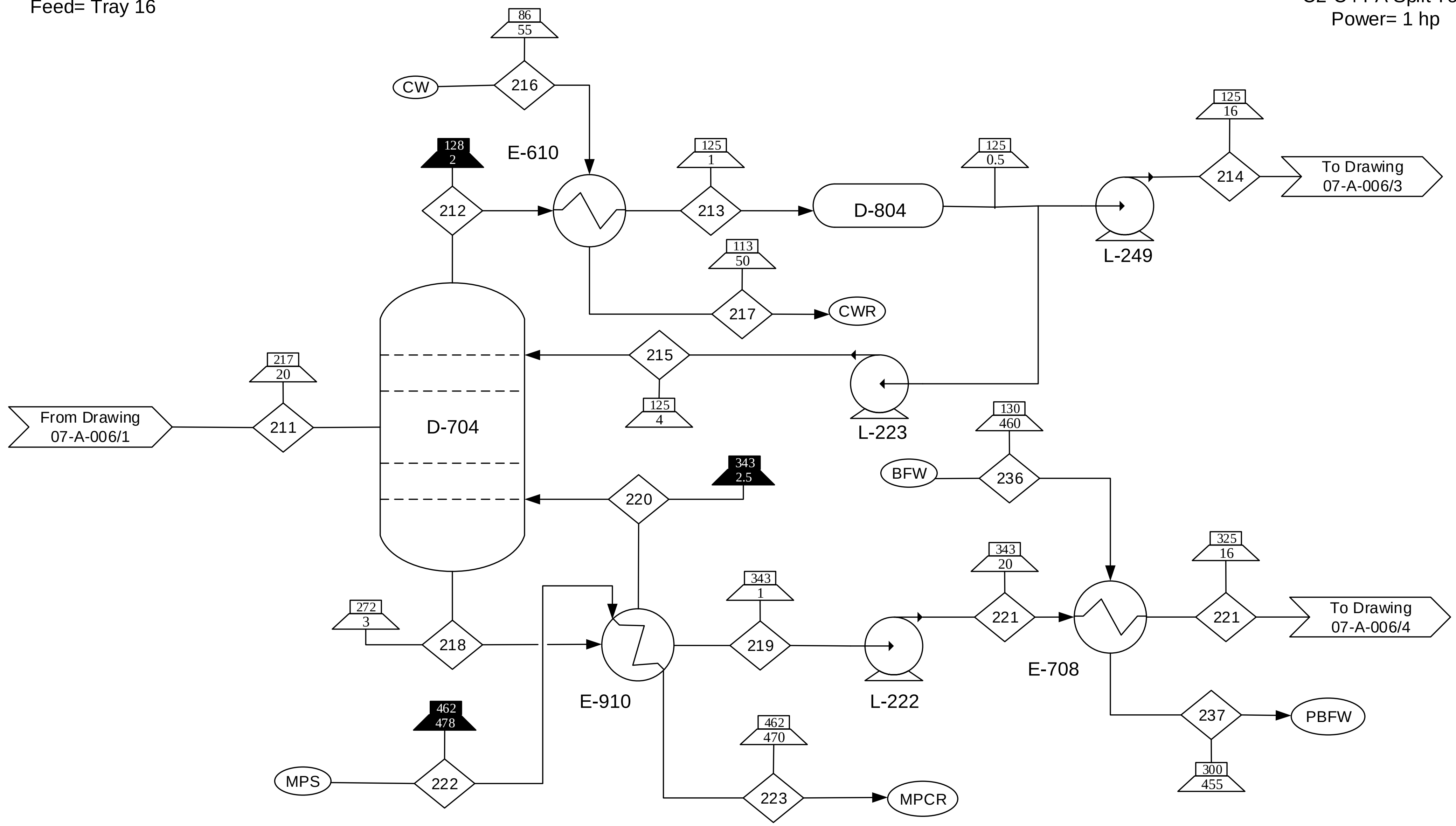
E-708 A/B
C6-C7 FA Cooler
Area= 30 ft^2
Duty= 2.0×10^5 Btu/hr

D-804 A/B
C2-C4 FA Split Reflux Drum
Length= 8ft
Diameter= 2ft

L-223 A/B
C2-C4 FA Split Reflux
Power= 7 hp

L-222 A/B
C2-C4 FA Split Bottoms
Power= 1 hp

L-249 A/B
C2-C4 FA Split Top
Power= 1 hp



Component/Stream (lb/min)	211	212	213	214	215	216	217	218	219	220	221	222	223	236	237
Fatty Acids C1-C18	290	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	0	50	50	11	40	0	0	0	0	0	0	0	0	0	0
Fatty Acids C3-C18	0	0	0	0	0	0	0	1100	280	820	280	0	0	0	0
Water	68	220	220	68	150	12000	12000	0	0	0	0	430	430	120	120
Total	360	270	270	80	190	12000	12000	1100	280	820	280	430	430	120	120

Notes

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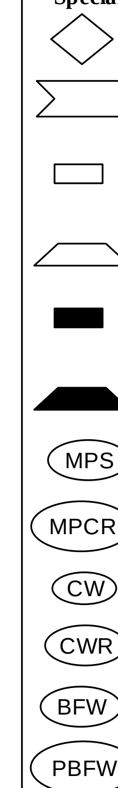
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



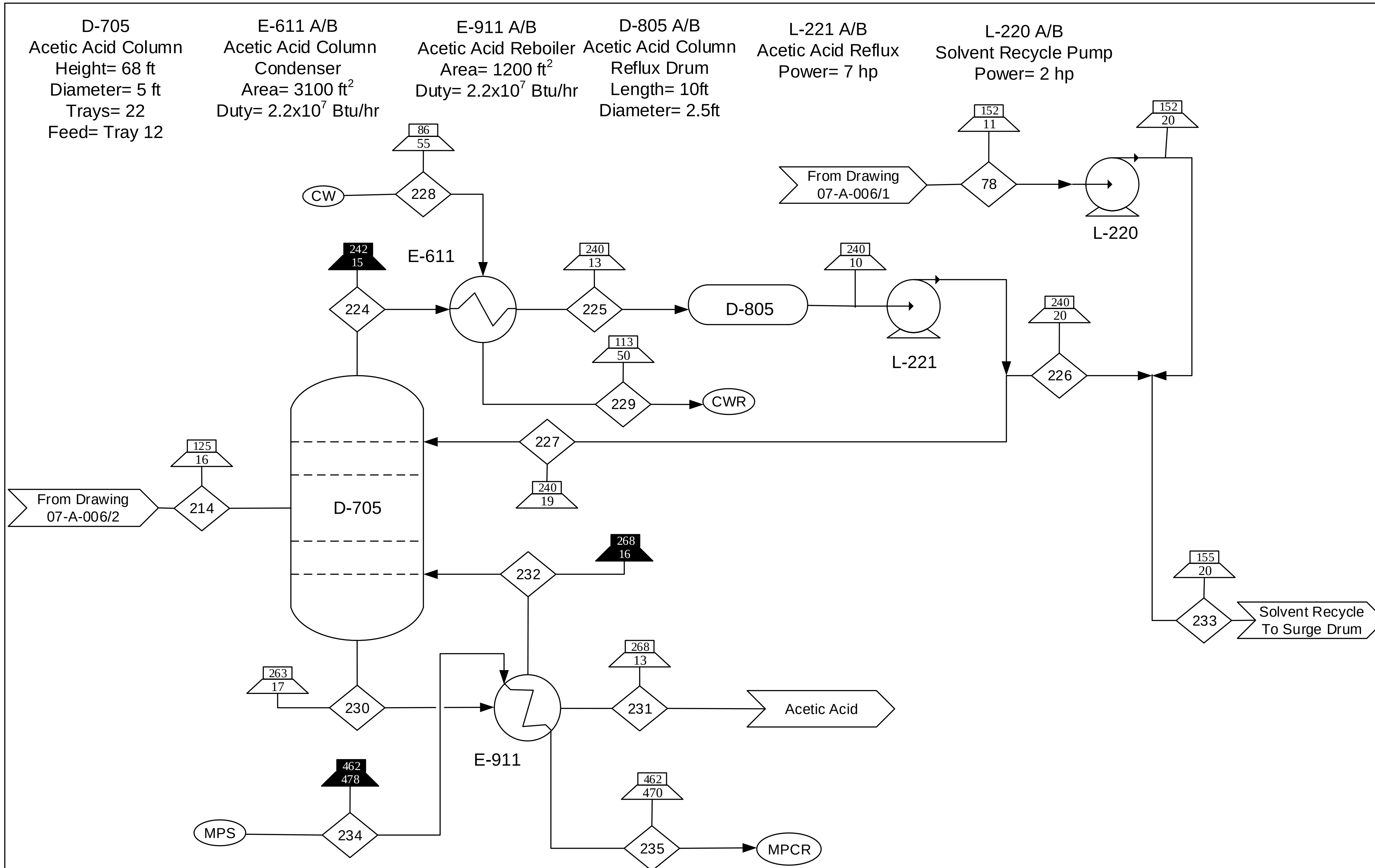
Reference Drawings:

Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
07-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-006/2	0



Component/Stream (lb/min)	78	214	224	225	226	227	228	229	230	231	232	233	234	235
Acetic Acid	0	11	0	0	0	0	0	0	930	11	920	0	0	0
Propionic Acid	Trace	Trace	0	0	0	0	0	0	5	Trace	4	0	0	0
TMA	340	0	0	0	0	0	0	0	0	0	0	340	0	0
Water	1300	68	310	310	68	240	13000	13000	0	0	0	1400	490	490
Total	1600	80	310	310	68	240	13000	13000	940	11	920	1700	490	490

Notes

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3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas
- MPS — Medium Pressure Steam
- MPCR — Medium Pressure Condensate Recycle
- CW — Cooling Water
- CWR — Cooling Water Recycle

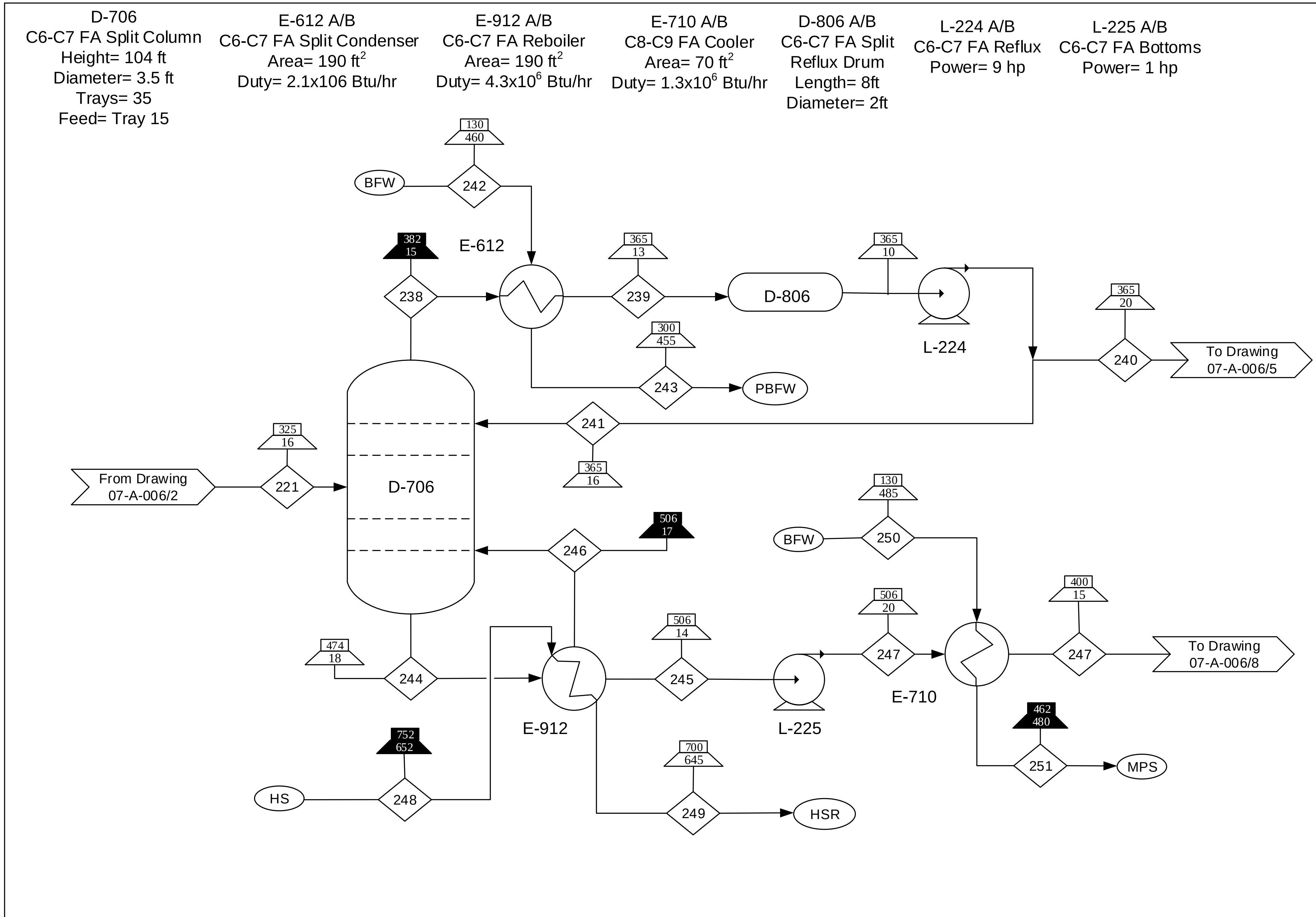
Reference Drawings:

Input/Output Diagram 00-A-004
Block Flow Diagram 00-A-005
Process Flow Diagrams 07-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-006/3	0



Component/Stream (lb/min)	221	238	239	240	241	242	243	244	245	246	247	248	249	250	251
Fatty Acids C3-C18	280	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fatty Acids C3-C6	0	130	130	23	110	0	0	0	0	0	0	0	0	0	0
Fatty Acids C7-C18	0	0	0	0	0	0	0	560	260	300	260	0	0	0	0
Water	0	0	0	0	0	1300	1300	0	0	0	0	950	950	20	20
Total	280	130	130	23	110	1300	1300	560	260	300	260	950	950	20	20

Notes

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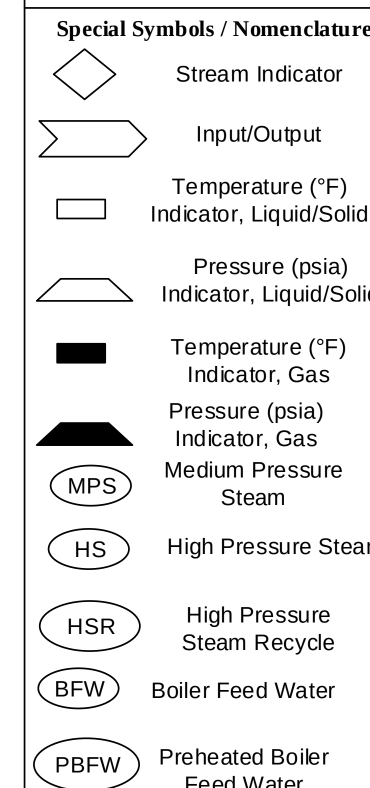
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.



Reference Drawings:

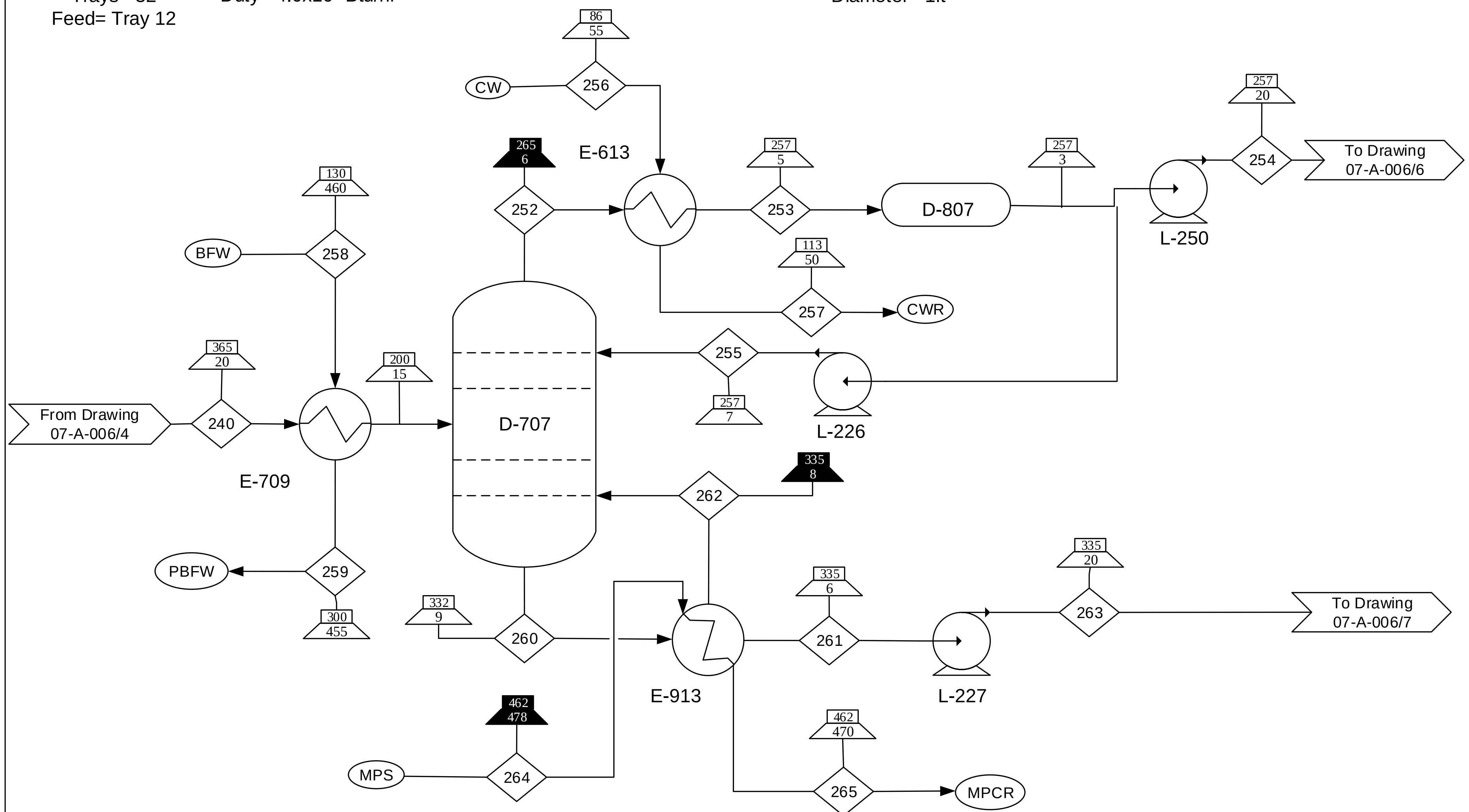
Input/Output Diagram 00-A-004
Block Flow Diagram 00-A-005
Process Flow Diagrams 07-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-006/4	0

D-707	E-613 A/B	E-913 A/B	E-709 A/B	D-807 A/B	L-226 A/B	L-227 A/B	L-250 A/B
C4-C5 FA Split Column	C4-C5 FA Column Condenser	C4-C5 FA Split Reboiler	C4-C5 FA Cooler	C4-C5 FA Split Reflux Drum	C4-C5 FA Reflux	C4-C5 FA Bottoms	C4-C5 FA Top
Height= 93 ft	Area= 50 ft^2	Area= 40 ft^2	Area= 30 ft^2	Length= 4ft	Power= 9 hp	Power= 1 hp	Power= 1 hp
Diameter= 1.5 ft	Duty= 4.0x10^5 Btu/hr	Duty= 5.2x10^5 Btu/hr	Duty= 1.7x10^5 Btu/hr	Diameter= 1ft			
Trays= 32							
Feed= Tray 12							



Component/Stream (lb/min)	240	252	253	254	255	256	257	258	259	260	261	262	263	264	265
Fatty Acids C3-C6	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fatty Acids C3-C4	0	21	21	4	17	0	0	0	0	0	0	0	0	0	0
Fatty Acids C5-C6	0	0	0	0	0	0	0	0	0	52	19	33	19	0	0
Water	0	0	0	0	0	240	240	100	100	0	0	0	0	11	11
Total	23	21	21	4	17	240	240	100	100	52	19	33	19	11	11

Notes

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3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°F) Indicator, Liquid/Solid

Pressure (psia) Indicator, Liquid/Solid

Temperature (°F) Indicator, Gas

Pressure (psia) Indicator, Gas

MPS Medium Pressure Steam

MPCR Medium Pressure Condensate Recycle

CW Cooling Water

CWR Cooling Water Recycle

BFW Boiler Feed Water

PBFW Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram 00-A-004

Block Flow Diagram 00-A-005

Process Flow Diagrams 07-A-006

Drawing Type

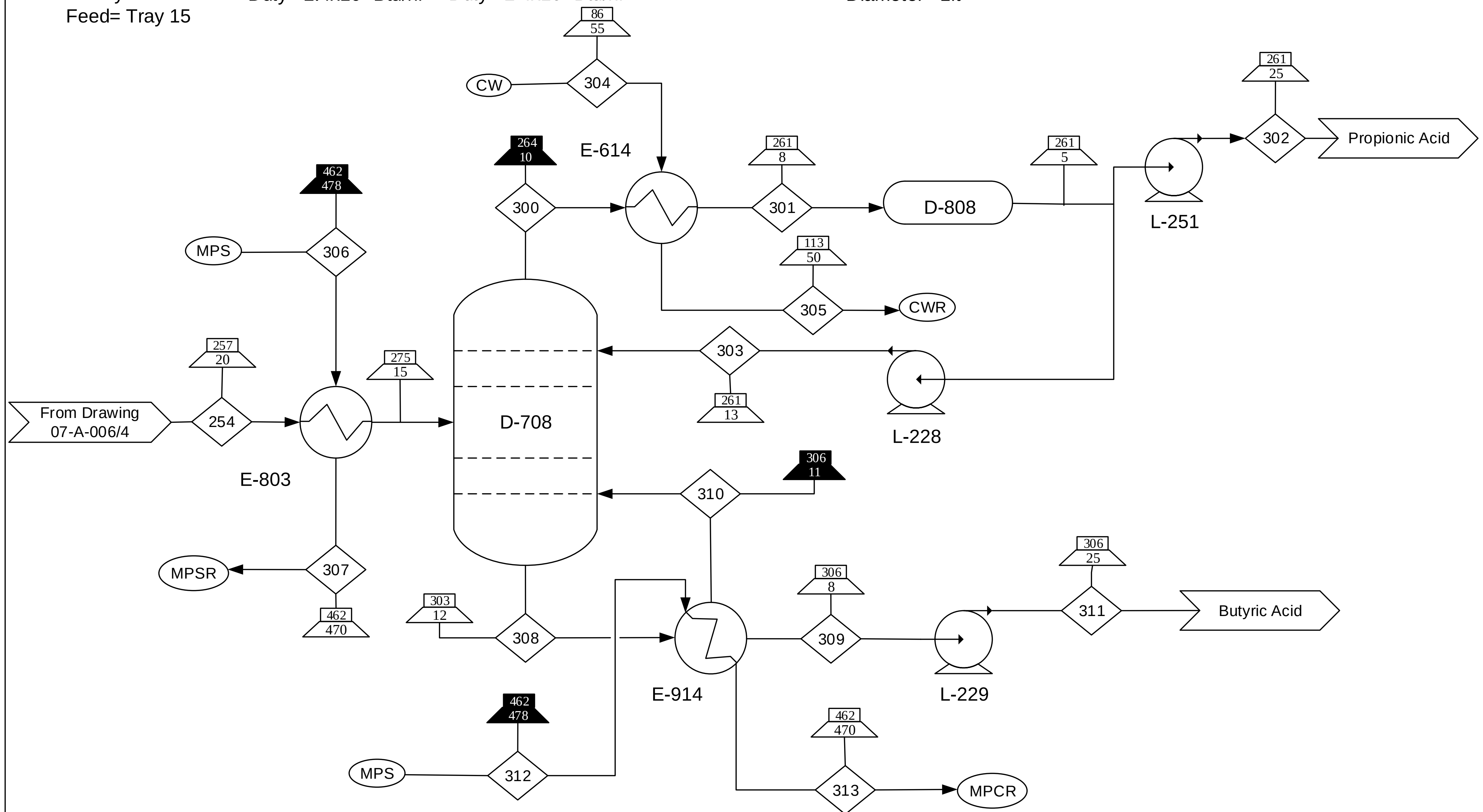
Process Flow Diagram

Title

Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-006/5	0

D-708	E-614 A/B	E-914 A/B	E-803 A/B	D-808 A/B	L-228 A/B	L-229 A/B	L-251 A/B
C3-C4 FA Product Column	C4-C5 FA Column Condenser	C3-C4 FA Product Reboiler	C3-C4 FA Heater	C3-C4 FA Product Reflux Drum	C3-C4 FA Reflux	C3-C4 Bottoms	C3-C4 Top
Height= 81 ft	Area= 30 ft^2	Area= 16 ft^2	Area= 2 ft^2	Length= 4ft	Power= 8 hp	Power= 2 hp	Power= 1 hp
Diameter= 1 ft	Duty= $2.4x10^5$ Btu/hr	Duty= $2.4x10^5$ Btu/hr	Duty= 2700 Btu/hr	Diameter= 1ft			
Trays= 28							
Feed= Tray 15							



Notes

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Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas
- MPS Medium Pressure Steam
- MPCR Medium Pressure Condensate Recycle
- CW Cooling Water
- CWR Cooling Water Recycle
- BFW Boiler Feed Water
- PBFW Preheated Boiler Feed Water

Component/Stream (lb/min)	254	300	301	302	303	304	305	306	307	308	309	310	311	312	313
Fatty Acids C3-C4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	0	12	12	1	11	0	0	0	0	0	0	0	0	0	0
Butyric Acid	0	0	0	0	0	0	0	0	0	16	2	14	2	0	0
Water	0	0	0	0	0	150	150	1	1	0	0	0	0	5	5
Total	4	12	12	1	11	150	150	1	1	16	2	14	2	5	5

Reference Drawings:

Input/Output Diagram 00-A-004

Block Flow Diagram 00-A-005

Process Flow Diagrams 07-A-006

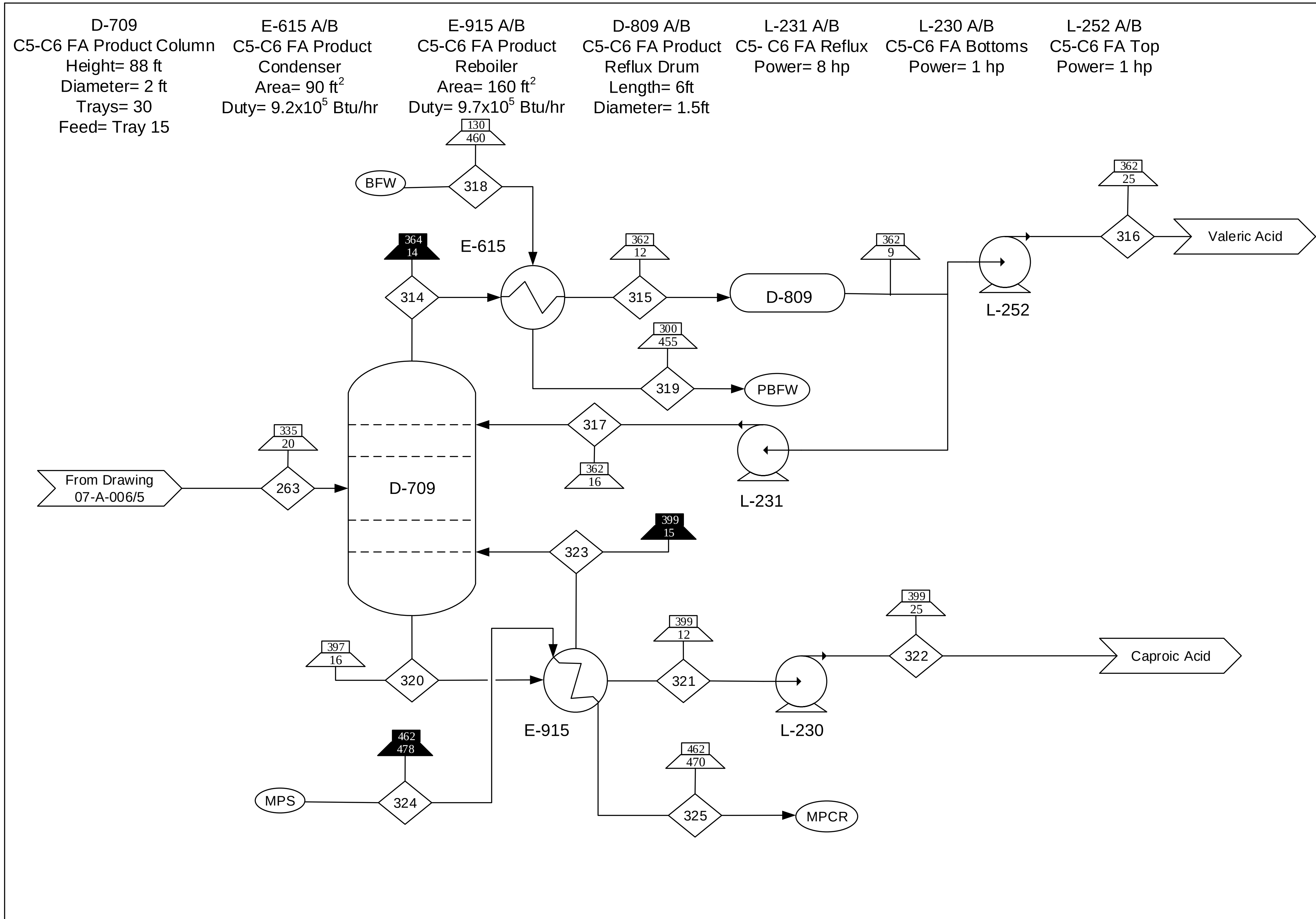
Drawing Type

Process Flow Diagram

Title

Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-006/6	0



Notes

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3. Mass balances are shown in lb/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°F) Indicator, Liquid/Solid

Pressure (psia) Indicator, Liquid/Solid

Temperature (°F) Indicator, Gas

Pressure (psia) Indicator, Gas

MPS Medium Pressure Steam

MPCR Medium Pressure Condensate Recycle

BFW Boiler Feed Water

PBFW Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
07-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-006/7	0

Component/Stream (lb/min)	263	314	315	316	317	318	319	320	321	322	323	324	325
Fatty Acids C5-C6	19	0	0	0	0	0	0	0	0	0	0	0	0
Valeric Acid	0	60	60	7	53	0	0	0	0	0	0	0	0
Caproic Acid	0	0	0	0	0	0	0	80	12	12	68	0	0
Water	0	0	0	0	0	570	570	0	0	0	0	21	21
Total	19	60	60	7	53	570	570	80	12	12	68	21	21

D-710
C8-C9 FA Split Column
Height= 81 ft
Diameter= 7 ft
Trays= 26
Feed= Tray 15

E-616 A/B
C8-C9 FA Split Condenser
Area= 460 ft^2
Duty= 5.6x10^6 Btu/hr

E-916 A/B
C8-C9 FA Reboiler
Area= 280 ft^2
Duty= 6.5x10^6 Btu/hr

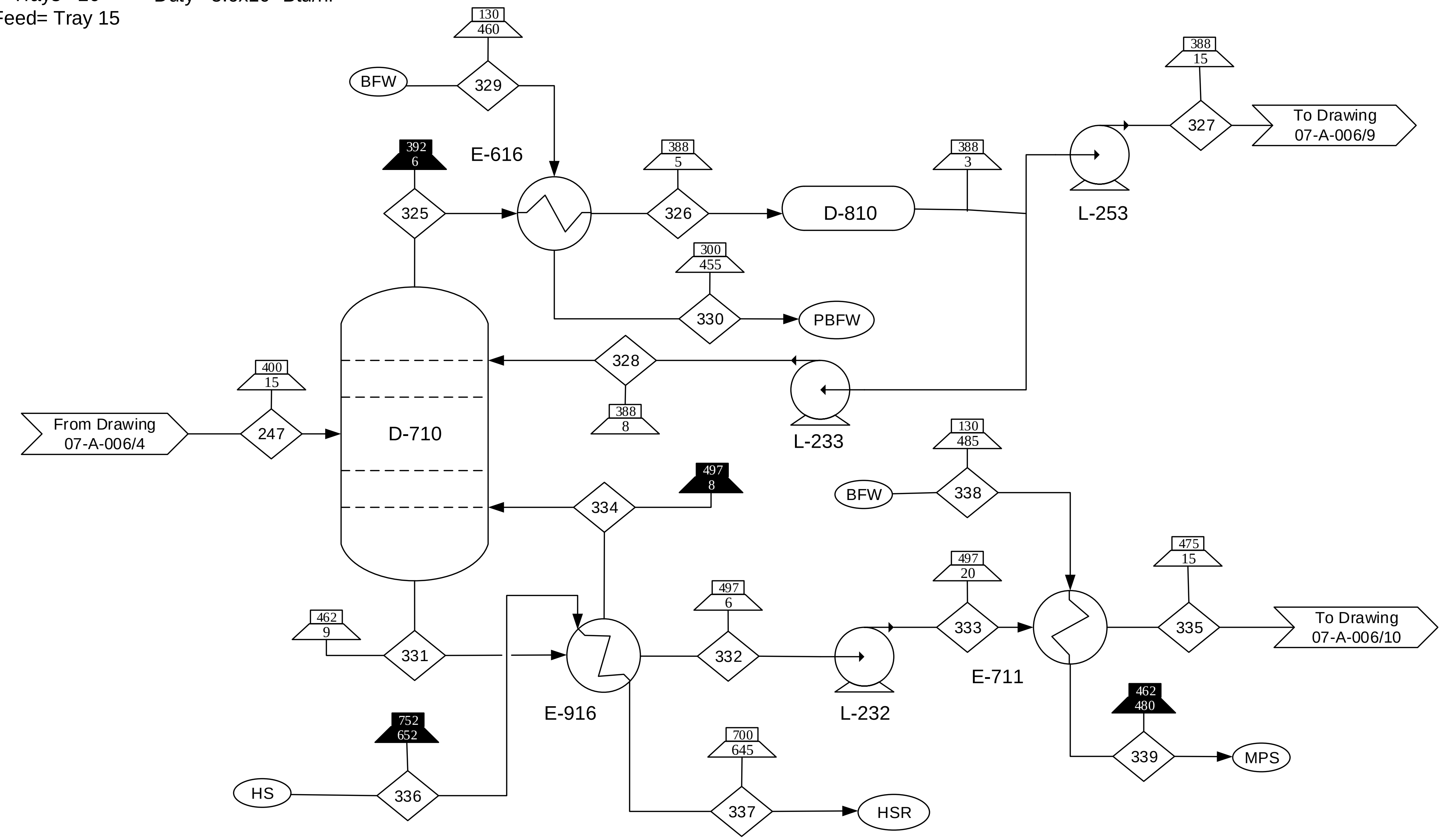
E-711 A/B
C10-C11 FA Cooler
Area= 550 ft^2
Duty= 4.5x10^6 Btu/hr

D-810 A/B
C8-C9 FA Split Reflux Drum
Length= 10ft
Diameter= 2.5ft

L-233 A/B
C8-C9 FA Reflux
Power= 7 hp

L-232 A/B
C8-C9 FA Bottoms
Power= 1 hp

L-253 A/B
C8-C9 FA Top
Power= 1 hp



Component/Stream (lb/min)	247	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339
Fatty Acids C7-C18	260	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fatty Acids C7-C8	0	410	410	57	350	0	0	0	0	0	0	0	0	0	0	0
Fatty Acids C9-C18	0	0	0	0	0	0	0	700	200	200	500	200	0	0	0	0
Water	0	0	0	0	0	3400	3400	0	0	0	0	0	1400	1400	4	4
Total	260	410	410	57	350	3400	3400	700	200	200	500	200	1400	1400	4	4

Notes

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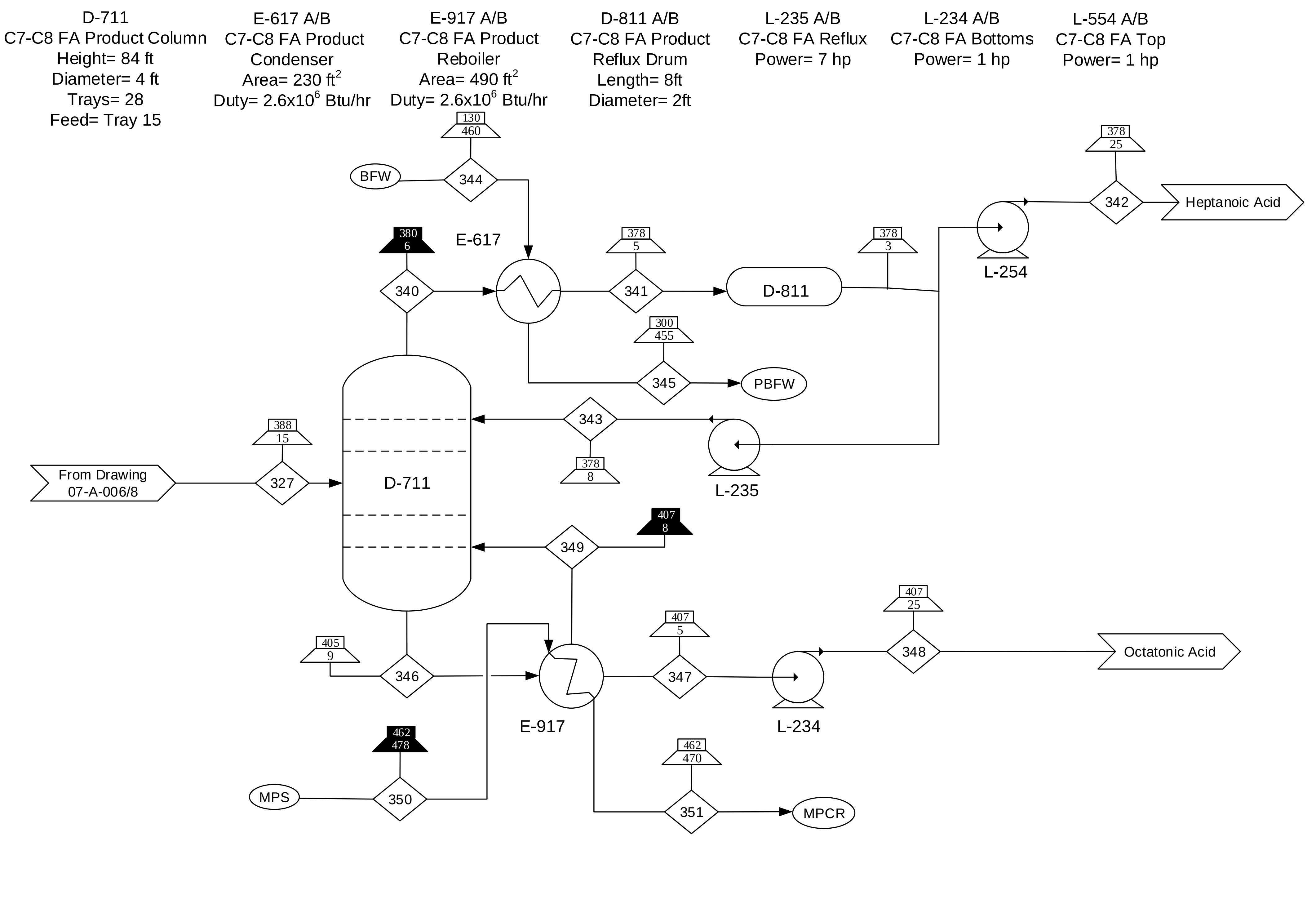
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
MPS Medium Pressure Steam
HS High Pressure Steam
HSR High Pressure Steam Recycle
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

Reference Drawings:
Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-05
Process Flow Diagrams
07-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-006/8	0



Component/Stream (lb/min)	327	340	341	342	343	344	345	346	347	348	349	350	351
Fatty Acids C7-C8	57	0	0	0	0	0	0	0	0	0	0	0	0
Heptanoic Acid	0	190	190	33	160	0	0	0	0	0	0	0	0
Octanoic Acid	0	0	0	0	0	0	0	230	24	24	210	0	0
Water	0	0	0	0	0	1600	1600	0	0	0	0	57	57
Total	57	190	190	33	160	1600	1600	230	24	24	210	57	57

Notes

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Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
MPS Medium Pressure Steam
MPCR Medium Pressure Condensate Recycle
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

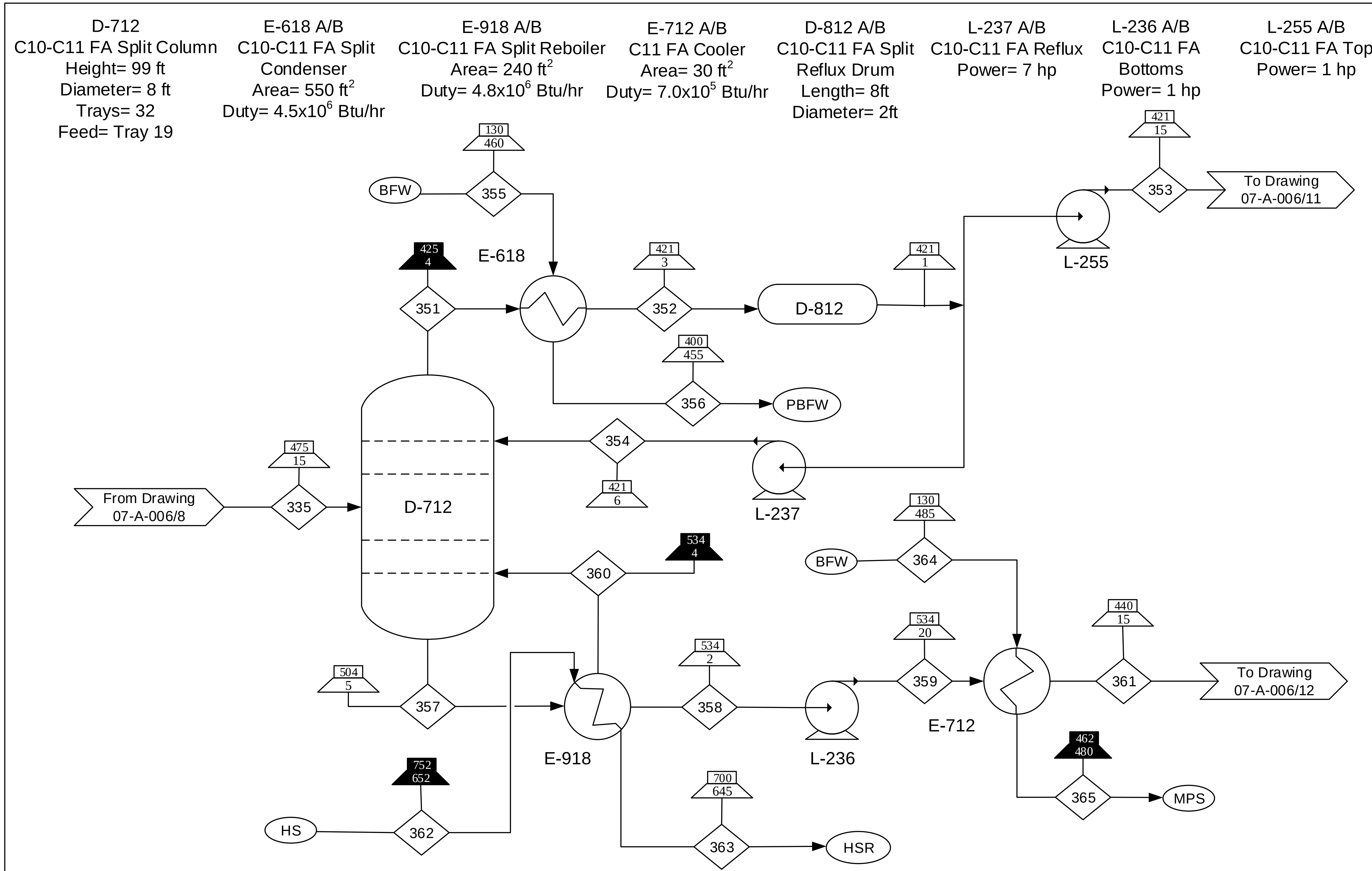
Reference Drawings:

Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
07-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-006/9	0

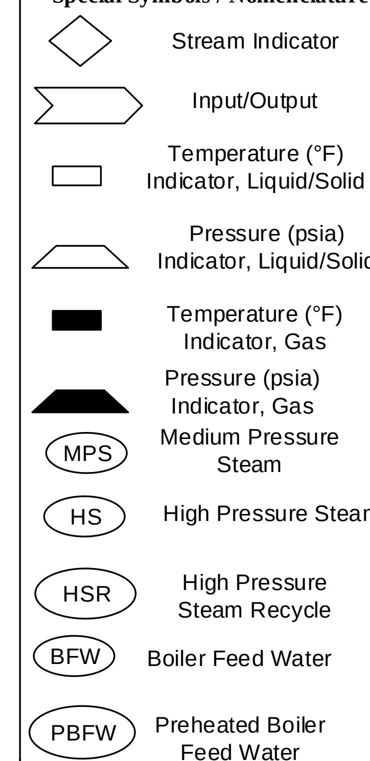


Component/Stream (lb/min)	335	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365
Fatty Acids C9-C18	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fatty Acids C9-C10	0	380	380	52	330	0	0	0	0	0	0	0	0	0	0	0
Fatty Acids C11-C18	0	0	0	0	0	0	0	560	150	150	410	150	0	0	0	0
Water	0	0	0	0	0	270	270	0	0	0	0	0	1100	1100	11	11
Total	200	380	380	52	330	270	270	560	150	150	410	150	1100	1100	11	11

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



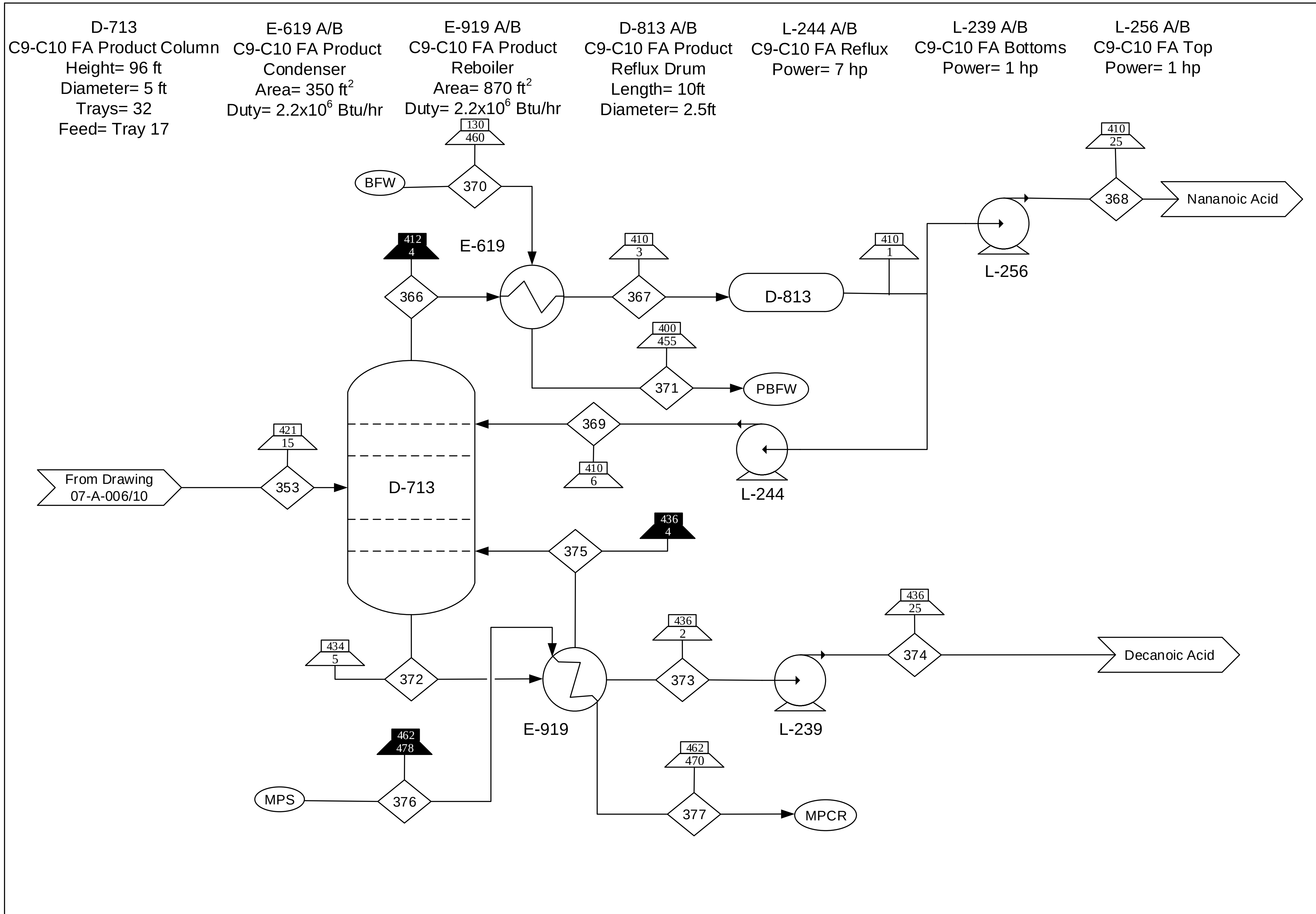
Reference Drawings:

Input/Output Diagram 00-A-004
Block Flow Diagram 00-A-005
Process Flow Diagrams 07-A-006

Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-006/10	0



Notes
1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature
- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas
- MPS: Medium Pressure Steam
- MPCR: Medium Pressure Condensate Recycle
- BFW: Boiler Feed Water
- PBFW: Preheated Boiler Feed Water

Reference Drawings:
Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
07-A-006

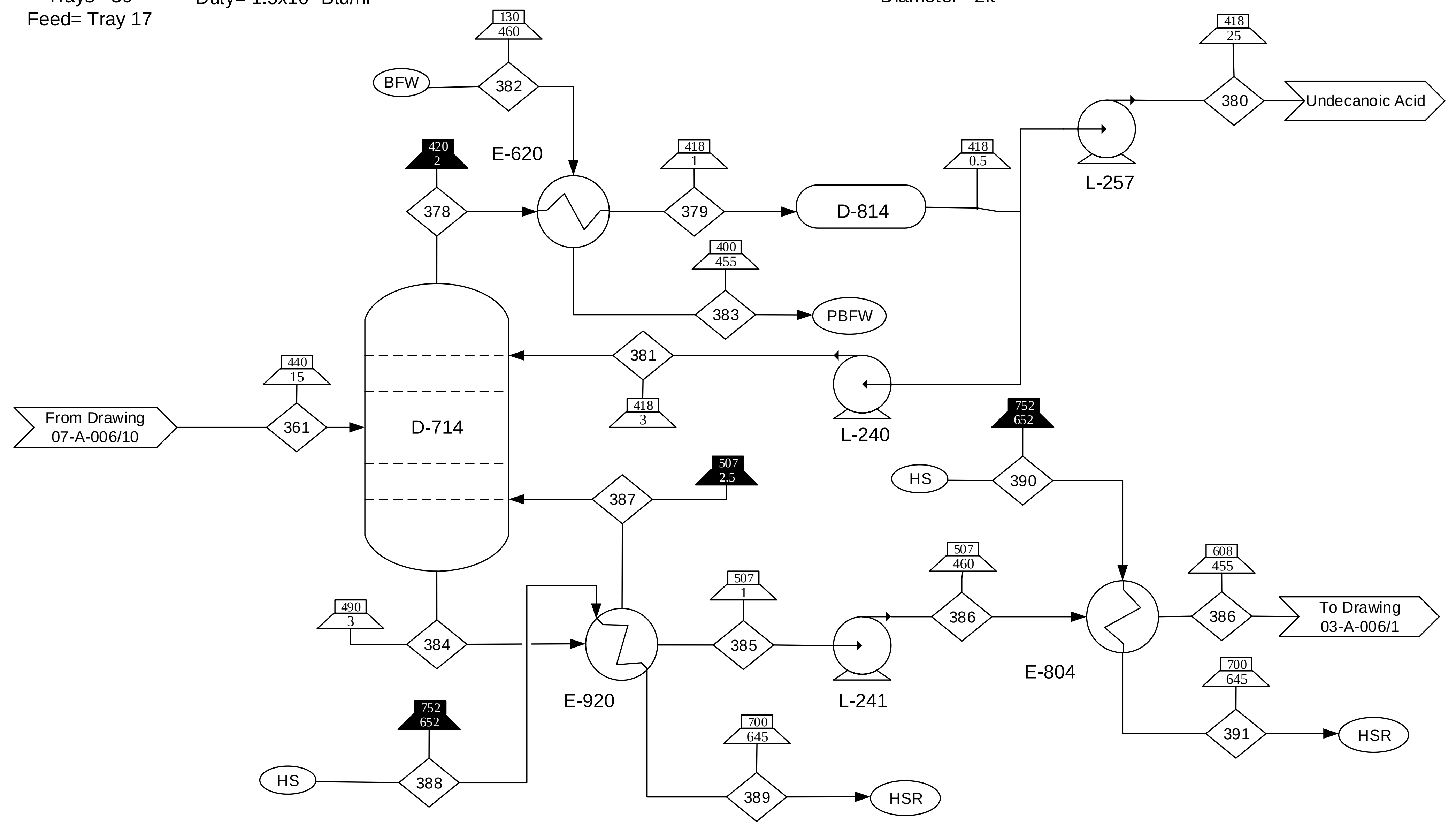
Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-006/11	0

Component/Stream (lb/min)	353	366	367	368	369	370	371	372	373	374	375	376	377
Fatty Acids C9-C10	52	0	0	0	0	0	0	0	0	0	0	0	0
Nananoic Acid	0	180	180	27	150	0	0	0	0	0	0	0	0
Decanoic Acid	0	0	0	0	0	0	0	220	25	25	190	0	0
Water	0	0	0	0	0	130	130	0	0	0	0	50	50
Total	52	180	180	27	150	130	130	220	25	25	190	50	50

D-714	E-620 A/B	E-920 A/B	E-804 A/B	D-814 A/B	L-240 A/B	L-241 A/B	L-257 A/B
C11 FA Product Column Height= 91 ft Diameter= 5.5 ft Trays= 30 Feed= Tray 17	C11 FA Product Condenser Area= 190 ft^2 Duty= $1.5x10^6$ Btu/hr	C11 FA Product Reboiler Area= 90 ft^2 Duty= $1.9x10^6$ Btu/hr	Fatty Acid Decarbox Heater Area= 60 ft^2 Duty= $7.0x10^5$ Btu/hr	C11 FA Product Reflux Drum Length= 8ft Diameter= 2ft	C11 FA Reflux Power= 7 hp	C11 FA Bottoms Power= 9 hp	C11 FA Top Power= 3 hp



Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas
- HS: High Pressure Steam
- HSR: High Pressure Steam Recycle
- BFW: Boiler Feed Water
- PBFW: Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-004
Block Flow Diagram
00-A-005
Process Flow Diagrams
03-A-006
07-A-006

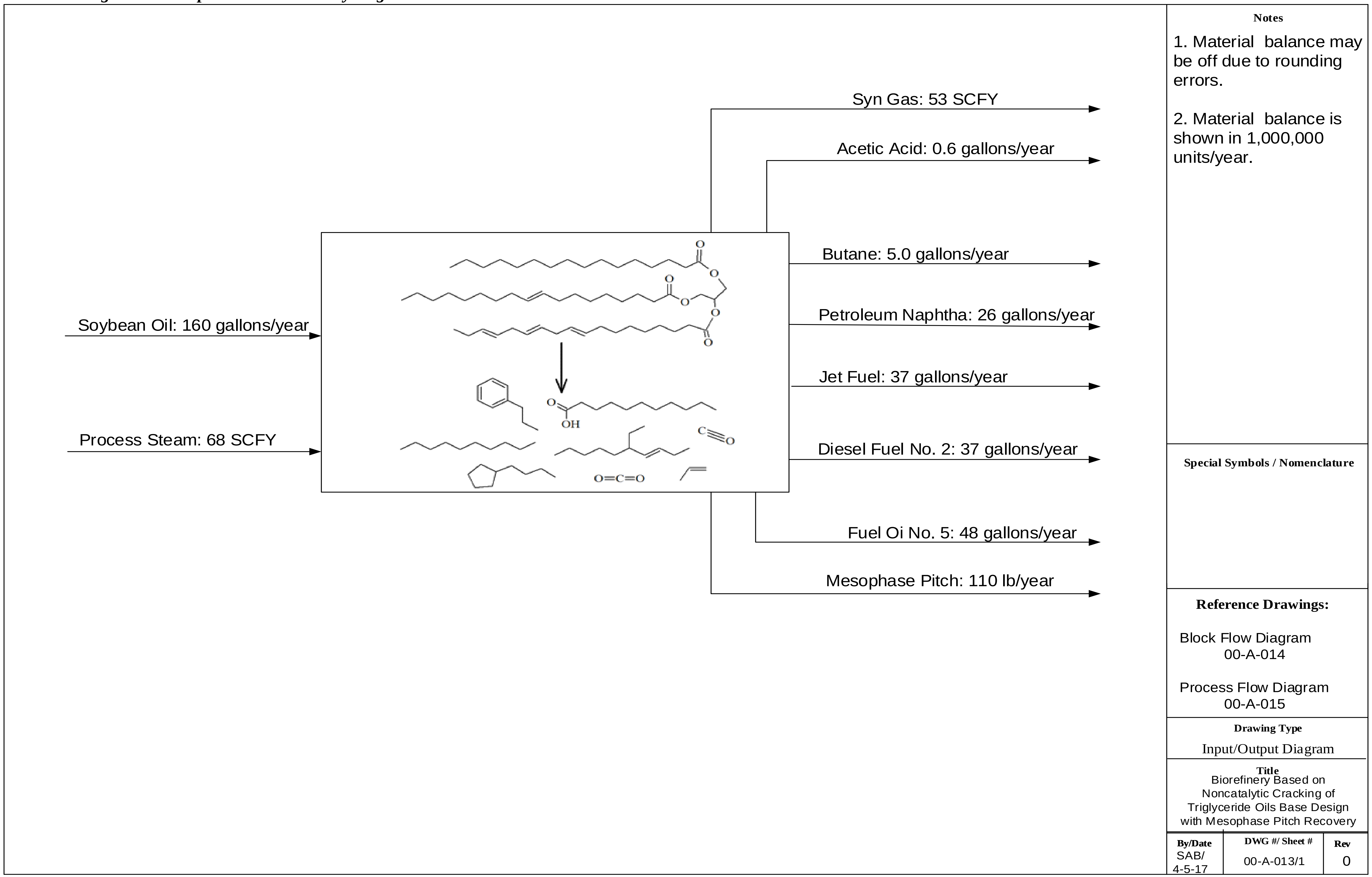
Component/Stream (lb/min)	361	378	379	380	381	382	383	384	385	386	387	388	389	390	391
Fatty Acids C11-C18	150	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undecanoic Acid	0	130	130	11	120	0	0	0	0	0	0	0	0	0	0
Fatty Acids C12-C18	0	0	0	0	0	0	0	310	140	140	170	0	0	0	0
Water	0	0	0	0	0	90	90	0	0	0	0	420	420	150	150
Total	150	130	130	11	120	90	90	310	140	140	170	420	420	150	150

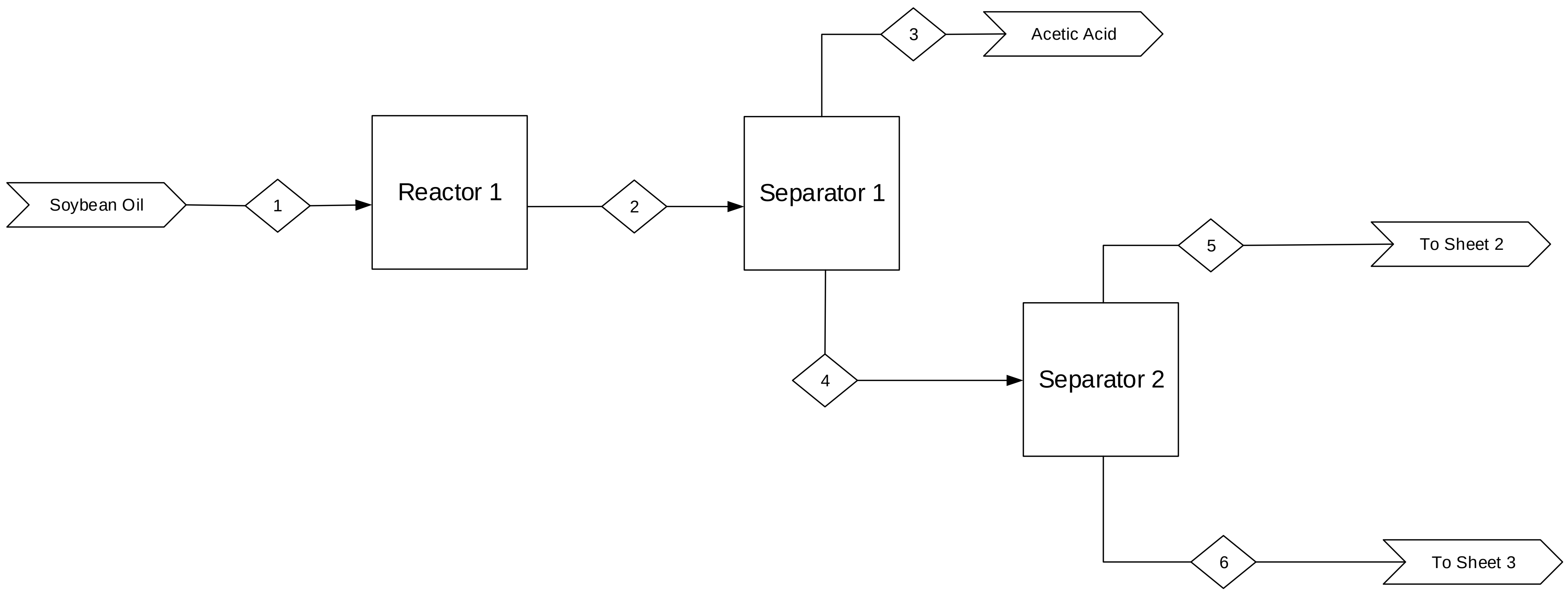
Drawing Type
Process Flow Diagram

Title
Biorefinery Fatty Acid Recovery Design – Fatty Acid Recovery Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-27-17	07-A-006/12	0

I.3. Base Design with Mesophase Pitch Recovery English Units





Component/Stream (lb/min)	1	2	3	4	5	6
Soybean Oil	2200	0	0	0	0	0
Acetic Acid	0	0	10	0	0	0
C1-C50	0	2200	0	2200	0	0
C1-C12	0	0	0	0	950	0
C12-C50	0	0	0	0	0	1200
Total	2200	2200	10	2200	950	1200

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 1: Crack incoming TG oil into fuel intermediates

Separator 1:Separate aqueous acetic acid from organic crackate

Separator 2: Separate the naphtha range fuel intermediates from the diesel range fuel intermediates

Special Symbols / Nomenclature

Input/Output

Stream Indicator

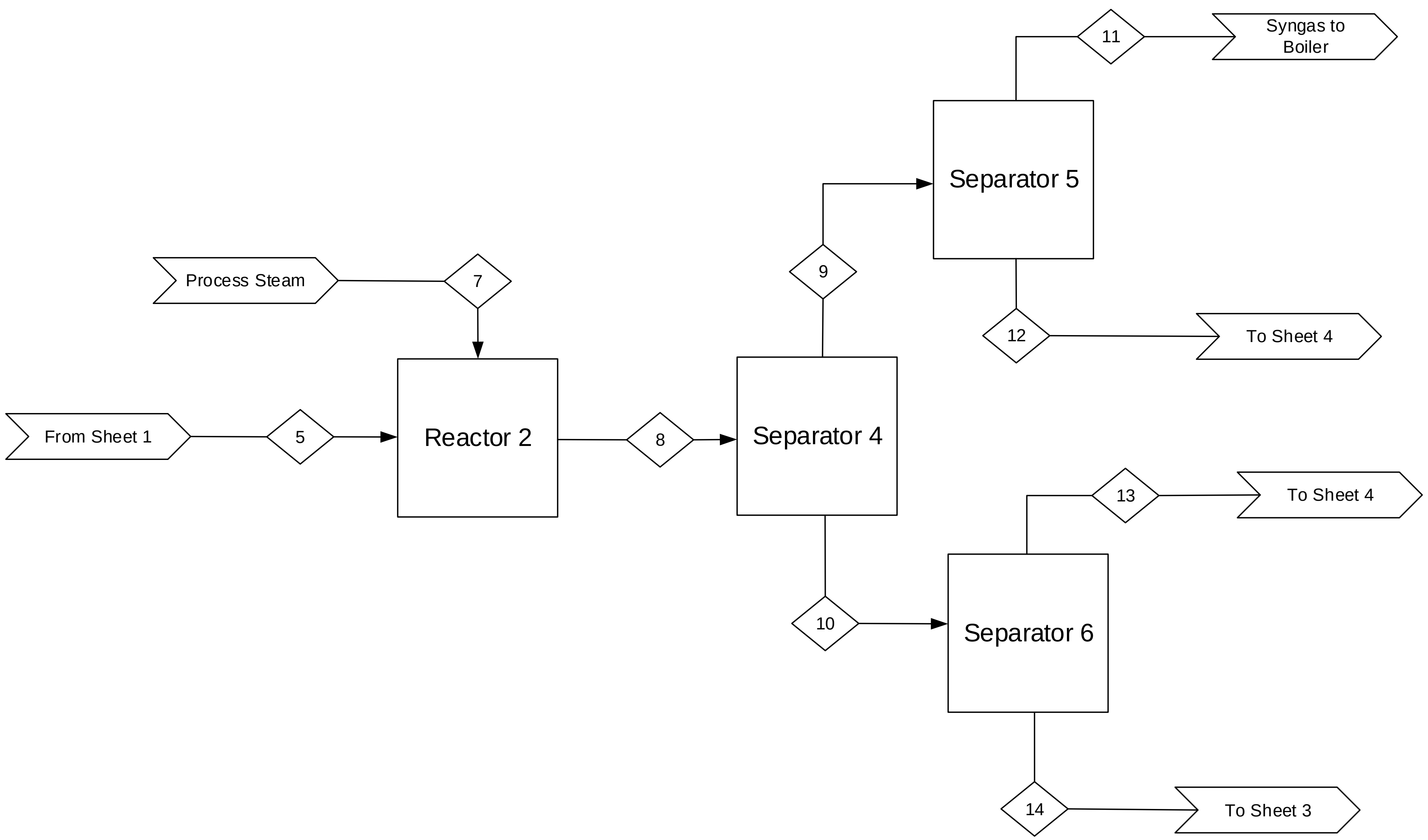
Reference Drawings:
Input/Output Diagram
00-A-013

Process Flow Diagram
00-A-015

Drawing Type
Block Flow Diagrams

Title
Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design with Mesophase Pitch Recovery

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-5-17	00-A-014/1	0



Component/Stream (lb/min)	5	7	8	9	10	11	12	13	14
C1-C12	950	0	970	0	0	0	0	0	0
Steam	0	15	0	0	0	0	0	0	0
C1-C6	0	0	0	530	0	0	0	0	0
C1-C3	0	0	0	0	0	350	0	0	0
C4-C6	0	0	0	0	0	0	180	0	0
C7-C10	0	0	0	0	0	0	0	140	0
C11-C13	0	0	0	0	0	0	0	0	300
C7-C13	0	0	0	0	440	0	0	0	0
Total	950	15	970	530	440	350	180	140	300

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 2: Reacts the carboxylic acids and alkenes to produce hydrocarbons.

Separator 4: Removes light ends from naphtha range fuel intermediates.

Separator 5: Removes syngas from butane and naphtha intermediates.

Separator 6: Separates petroleum naphtha intermediates from jet fuel range fuel intermediates.

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

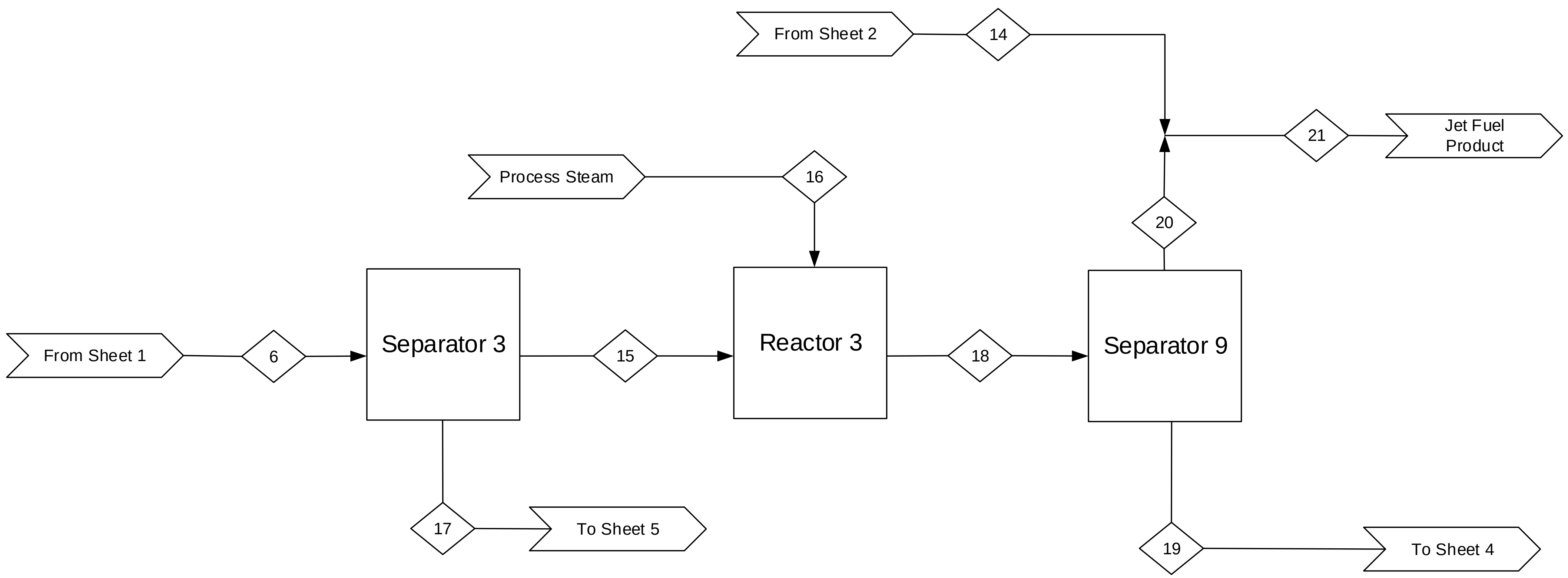
Input/Output Diagram
00-A-013

Process Flow Diagram
00-A-015

Drawing Type
Block Flow Diagram

Title
Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design with Mesophase Pitch Recovery

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-5-17	00-A-014/2	0



Component/Stream (lb/min)	6	14	15	16	17	18	19	20	21
Steam	0	0	0	20	0	0	0	0	0
C12-C50	1200	0	0	0	0	0	0	0	0
C30-C50	0	0	0	0	620	0	0	0	0
C12-C30	0	0	620	0	0	640	0	0	0
C13-C15	0	0	0	0	0	0	0	160	0
C11-C13	0	300	0	0	0	0	0	0	0
C11-C15	0	0	0	0	0	0	0	0	470
C15-C30	0	0	0	0	0	0	480	0	0
Total	1200	300	620	20	620	640	480	160	470

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 3: Reacts carboxylic acids and alkenes to produce hydrocarbons.

Separator 3: Separates diesel fuel range intermediates from the vacuum bottoms.

Separator 9: Separates jet fuel range fuel intermediates from diesel fuel range intermediates.

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-013

Process Flow Diagram
00-A-015

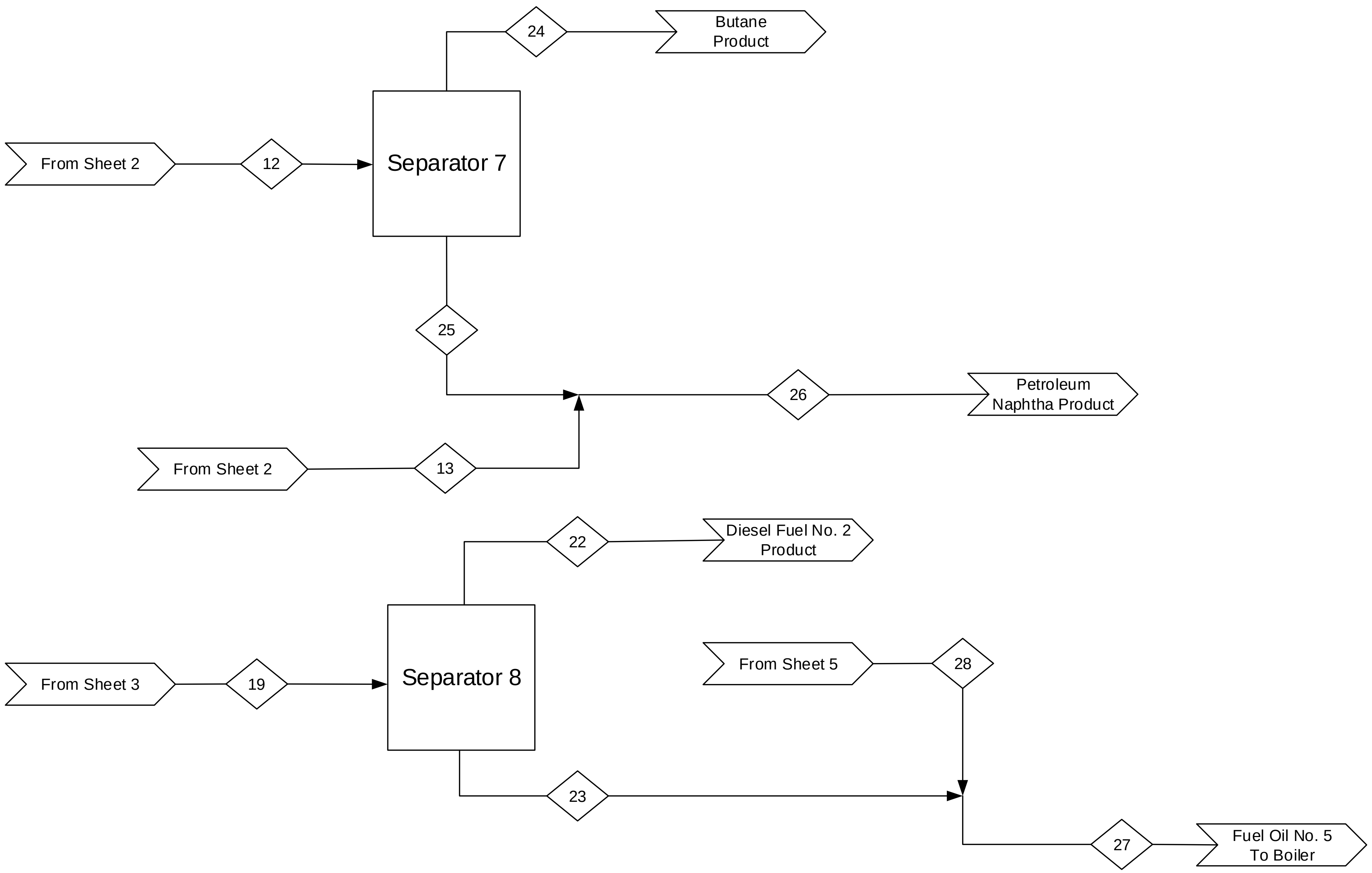
Drawing Type

Block Flow Diagram

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design with Mesophase Pitch Recovery

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-5-17	00-A-014/3	0



Component/Stream (lb/min)	12	13	19	22	23	24	25	26	27	28
C4-C6	180	0	0	0	0	0	0	0	0	0
C4	0	0	0	0	0	45	0	0	0	0
C5-C6	0	0	0	0	0	0	140	0	0	0
C7-C10	0	140	0	0	0	0	0	0	0	0
C5-C10	0	0	0	0	0	0	0	280	0	0
C15-C22	0	0	0	470	0	0	0	0	0	0
C23-C30	0	0	0	0	9	0	0	0	410	400
C15-C30	0	0	480	0	0	0	0	0	0	0
Total	180	140	480	470	9	45	140	280	410	400

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Separator 7: Separates butane byproduct from naphtha range intermediates.

Separator 8: Separates the diesel fuel no. 2 product from the fuel oi no 5. product.

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-013

Process Flow Diagram
00-A-015

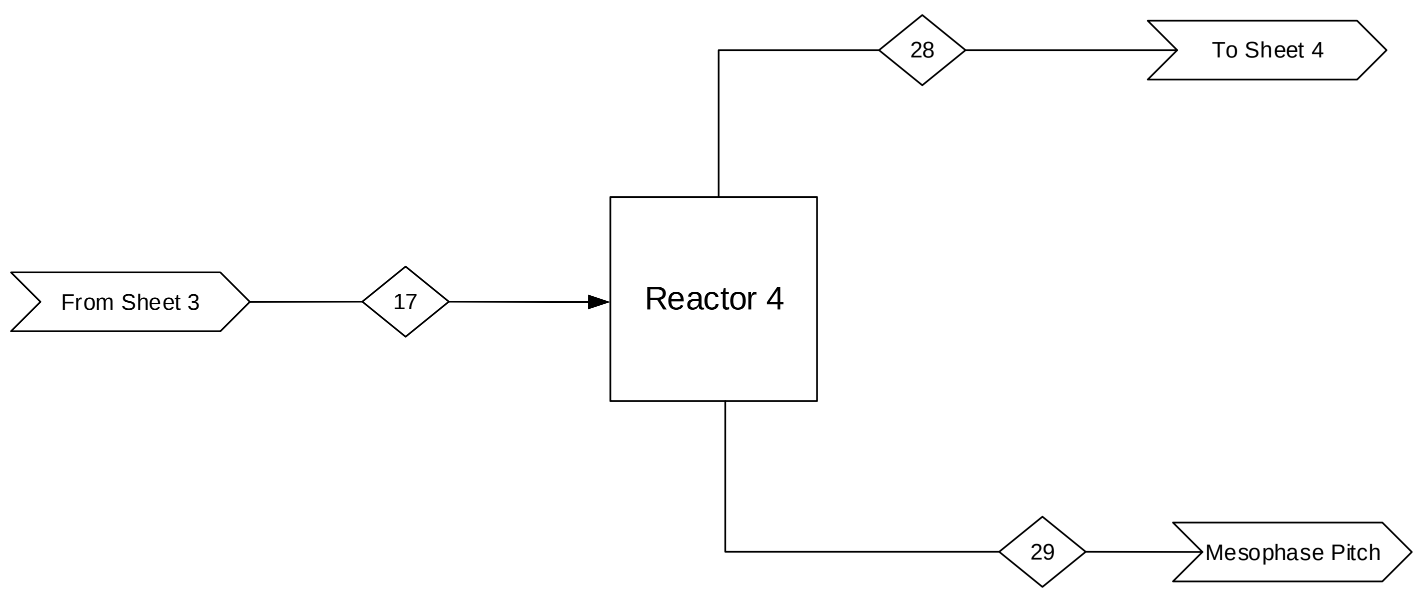
Drawing Type

Block Flow Diagram

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design with Mesophase Pitch Recovery

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-5-17	00-A-014/4	0

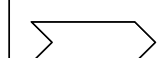


Component/Stream (lb/min)	17	28	29
C30-C50	620	0	0
C23-C30	0	400	0
Mesophase Pitch	0	0	220
Total	620	400	220

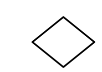
Notes

1. Drawing not to scale.
2. Mass balance may be off due to rounding.
3. Stream numbers do not correspond with PFD stream numbers.
4. Mass balances shown in lb/min.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Assume 100% separation in separators.
7. Reactor 4: Uses heat to produce mesophase pitch from vacuum bottoms, with production of fuel oil no. 5.

Special Symbols / Nomenclature



Input/Output



Stream Indicator

Reference Drawings:

Input/Output Diagram 00-A-013

Process Flow Diagram 00-A-015

Drawing Type

Block Flow Diagram

Title

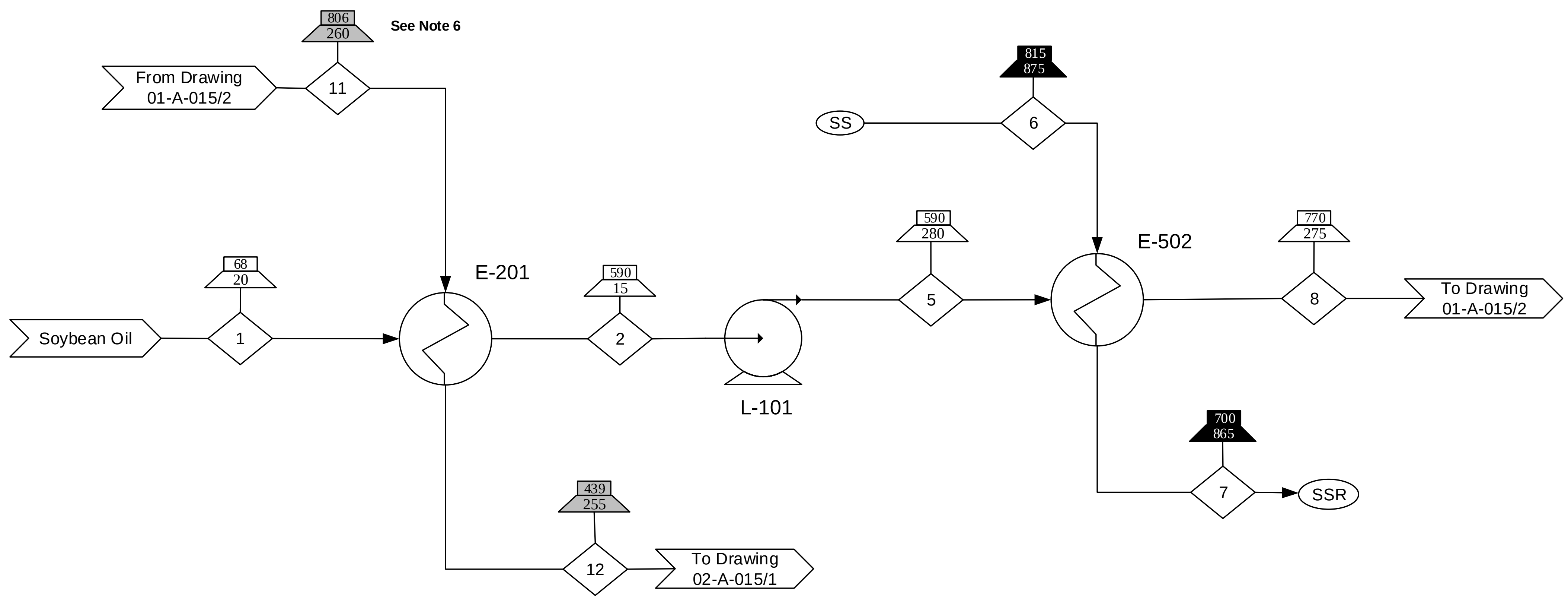
Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Base Design with Mesophase Pitch Recovery

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-5-17	00-A-014/4	0

E-201 A/B
Post Cracking Cooler
Area = 3400 ft^2
Duty = 4.9×10^7 Btu/hr

E-502 A/B
TTCR Preheat
Area = 4900 ft^2
Duty = 2.2×10^7 Btu/hr

L-101 A/B
PreCracking Pump
Power = 96 hp

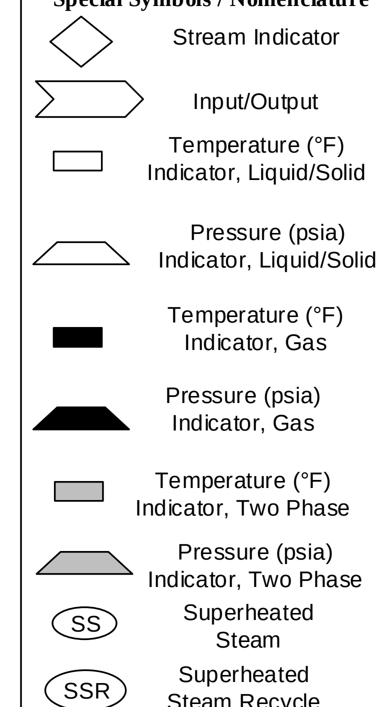


Component/Stream (lb/min)	1	2	5	6	7	8	11	12
Soybean Oil	2200	2200	2200	0	0	2200	0	0
C1-C50	0	0	0	0	0	0	2200	2200
Water	0	0	0	5300	5300	0	0	0
Total	2200	2200	2200	5300	5300	2200	2200	2200

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 11 and 12 is an organic, aqueous, gaseous three phase stream.

Special Symbols / Nomenclature



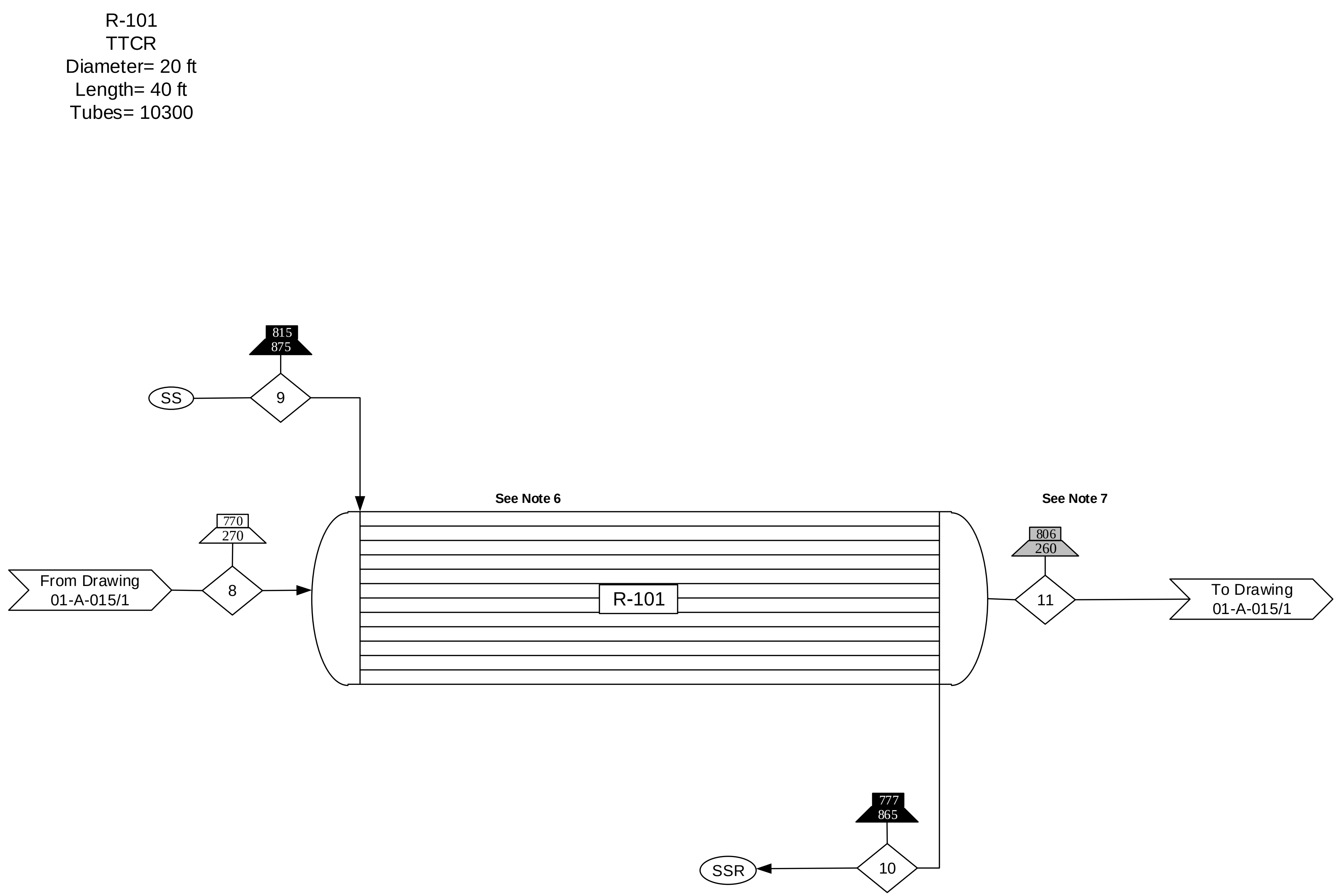
Reference Drawings:

Input/Output Diagram
00-A-013
Block Flow Diagrams
00-A-014
Process Flow Diagrams
01-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch- Thermal Cracking Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	01-A-015/1	0



Component/Stream (lb/min)	8	9	10	11
Soybean Oil	2200	0	0	0
C1-C50	0	0	0	2200
Water	0	18000	18000	0
Total	2200	18000	18000	2200

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in lb/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. R-101 has a residence time of 1.17 hr.

7. Stream 11 is composed of a gas phase stream with entrained liquid tars.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
SS Superheated Steam
SR Superheated Steam Recycle

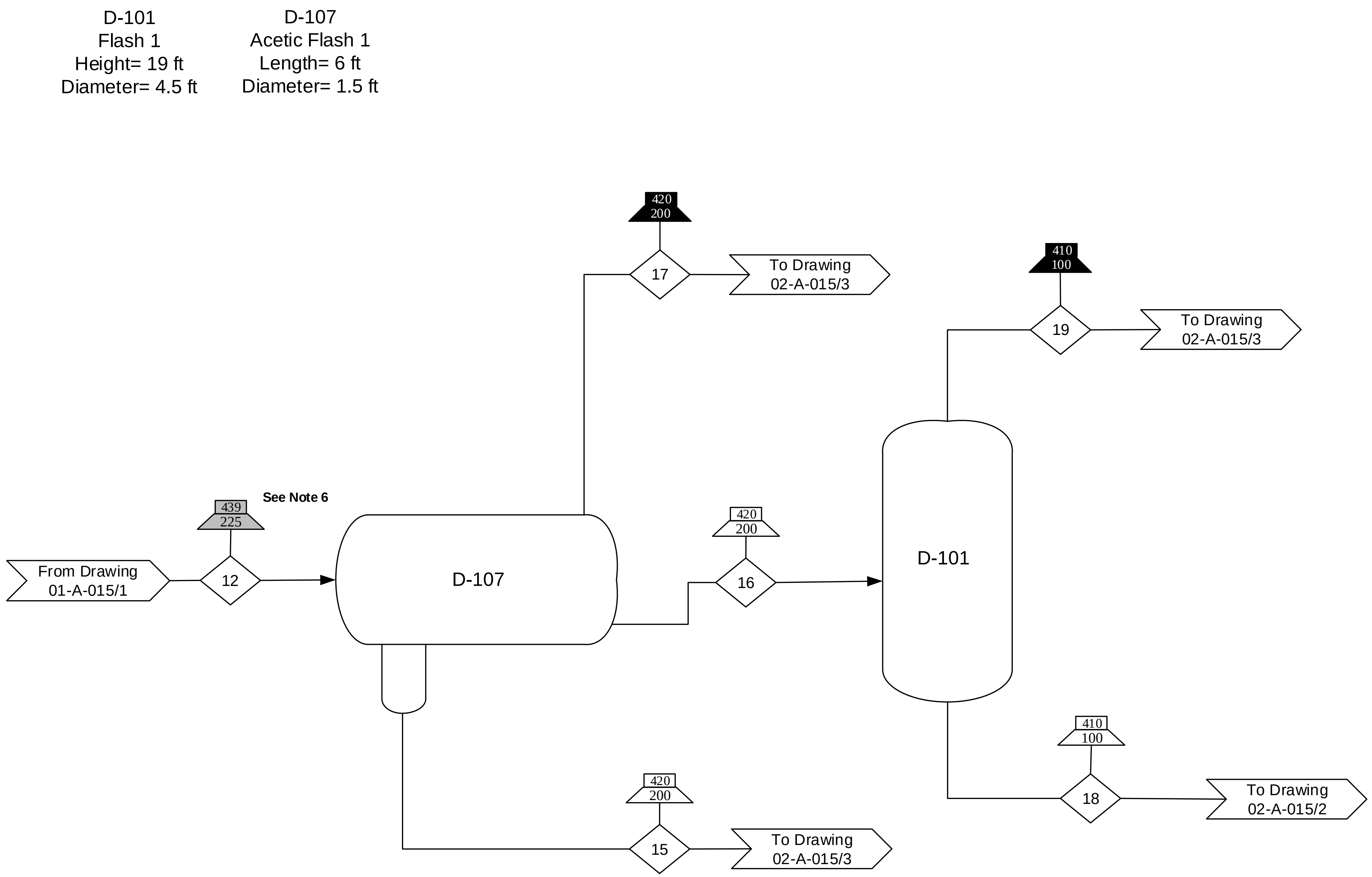
Reference Drawings:

Input/Output Diagrams
00-A-013
Block Flow Diagrams
00-A-014
Process Flow Diagrams
01-A-015
02-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch - Thermal Cracking Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	01-A-015/2	0



Component/Stream (lb/min)	12	15	16	17	18	19
C1-C50	2200	0	0	0	0	0
C1-C8	0	0	0	460	0	20
C7-C50	0	0	1700	0	1700	0
Acetic Acid	0	6	0	0	0	0
Propionic Acid	0	1	0	0	0	0
Total	2200	7	1700	460	1700	20

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 12 is composed of an aqueous and organic three phase stream.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas
- Temperature (°F) Indicator, Two Phase
- Pressure (psia) Indicator, Two Phase

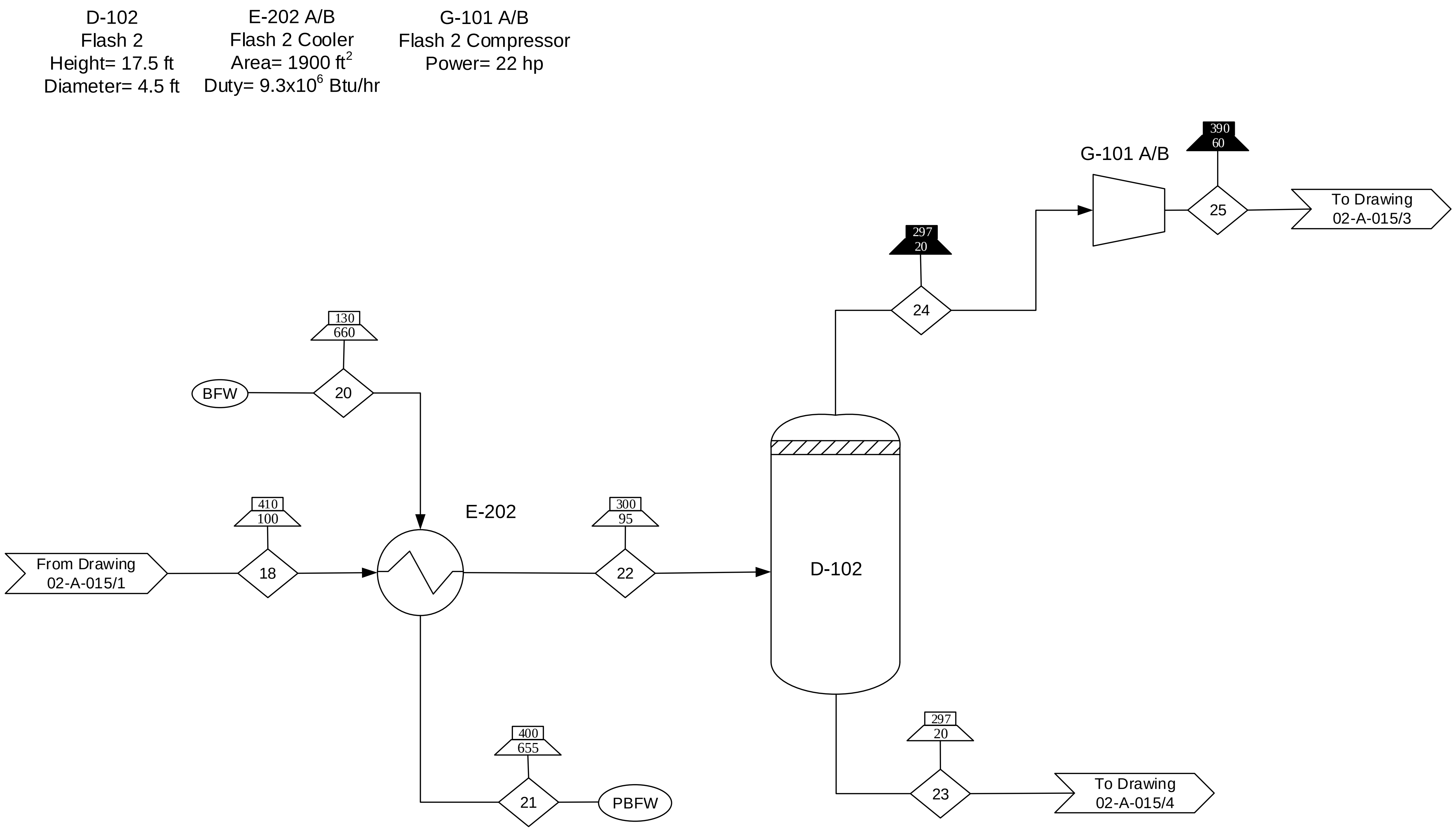
Reference Drawings:

Input/Output Diagram
00-A-013
Block Flow Diagram
00-A-014
Process Flow Diagrams
01-A-015
02-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	02-A-015/1	0



Component/Stream (lb/min)	18	20	21	22	23	24	25
C1-C8	0	0	0	0	0	20	20
C7-C50	1700	0	0	1700	1700	0	0
Water	0	190	190	0	0	0	0
Total	1700	190	190	1700	1700	20	20

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in lb/min.

4. Pumps operate at 65% efficiency.

5. Compressors operate at 55% efficiency.

6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°F) Indicator, Liquid/Solid

Pressure (psia) Indicator, Liquid/Solid

Temperature (°F) Indicator, Gas

Pressure (psia) Indicator, Gas

BFW Boiler Feed Water

PBFW Preheated Boiler Feed Water

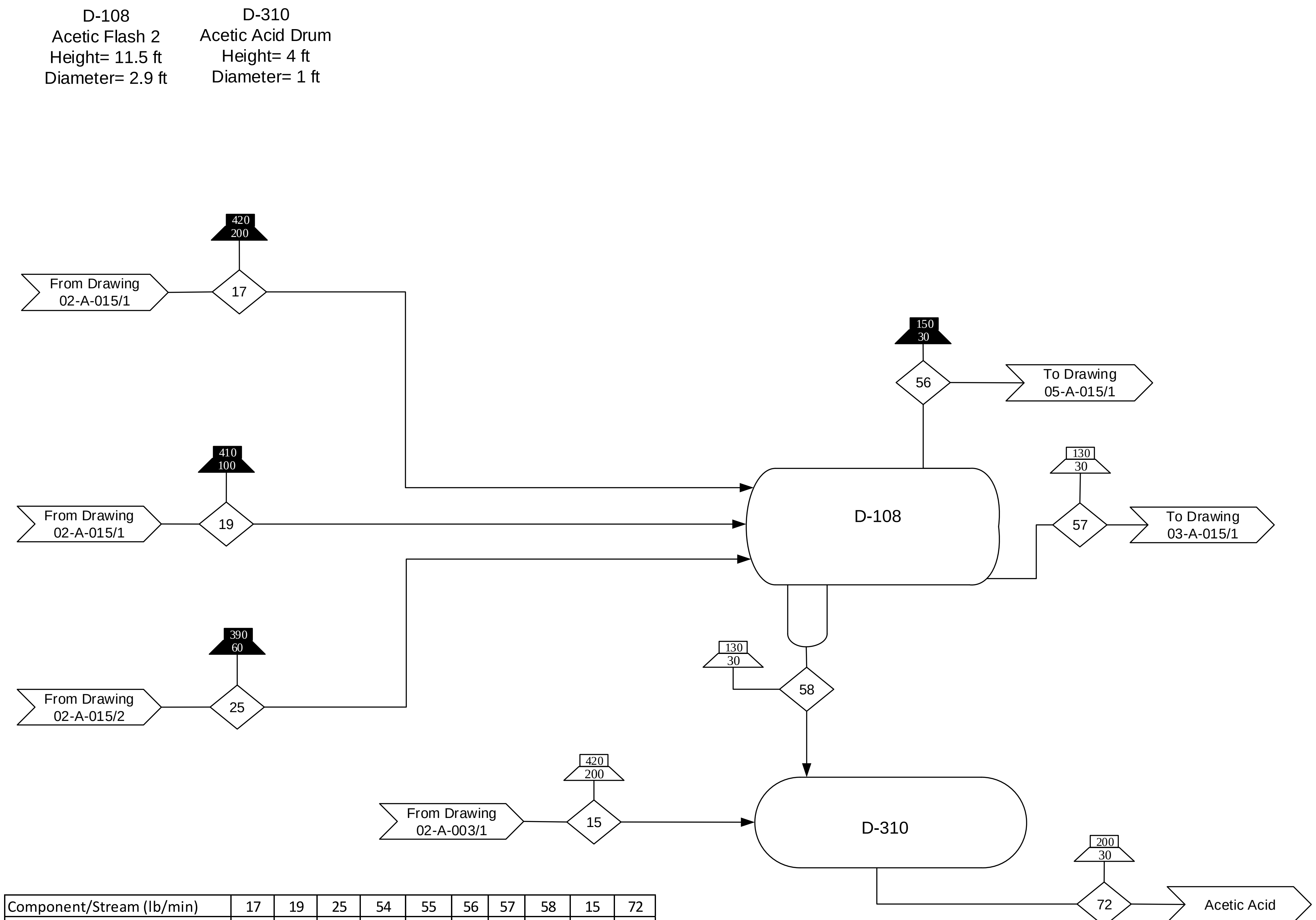
Reference Drawings:

Input/Output Diagrams
00-A-013
Block Flow Diagrams
00-A-014
Process Flow Diagrams
02-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	02-A-015/2	0



Component/Stream (lb/min)	17	19	25	54	55	56	57	58	15	72
C1-C8	460	20	20	0	0	0	0	0	0	0
C1-C6	0	0	0	0	0	380	0	0	0	0
C6-C8	0	0	0	0	0	0	120	0	0	0
Water	0	0	0	4100	4100	0	0	0	0	0
Acetic Acid	0	Trace	Trace	0	0	Trace	0	3	6	9
Propionic Acid	0	Trace	Trace	0	0	0	0	Trace	1	1
Total	460	20	20	4100	4100	380	120	3	7	10

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas

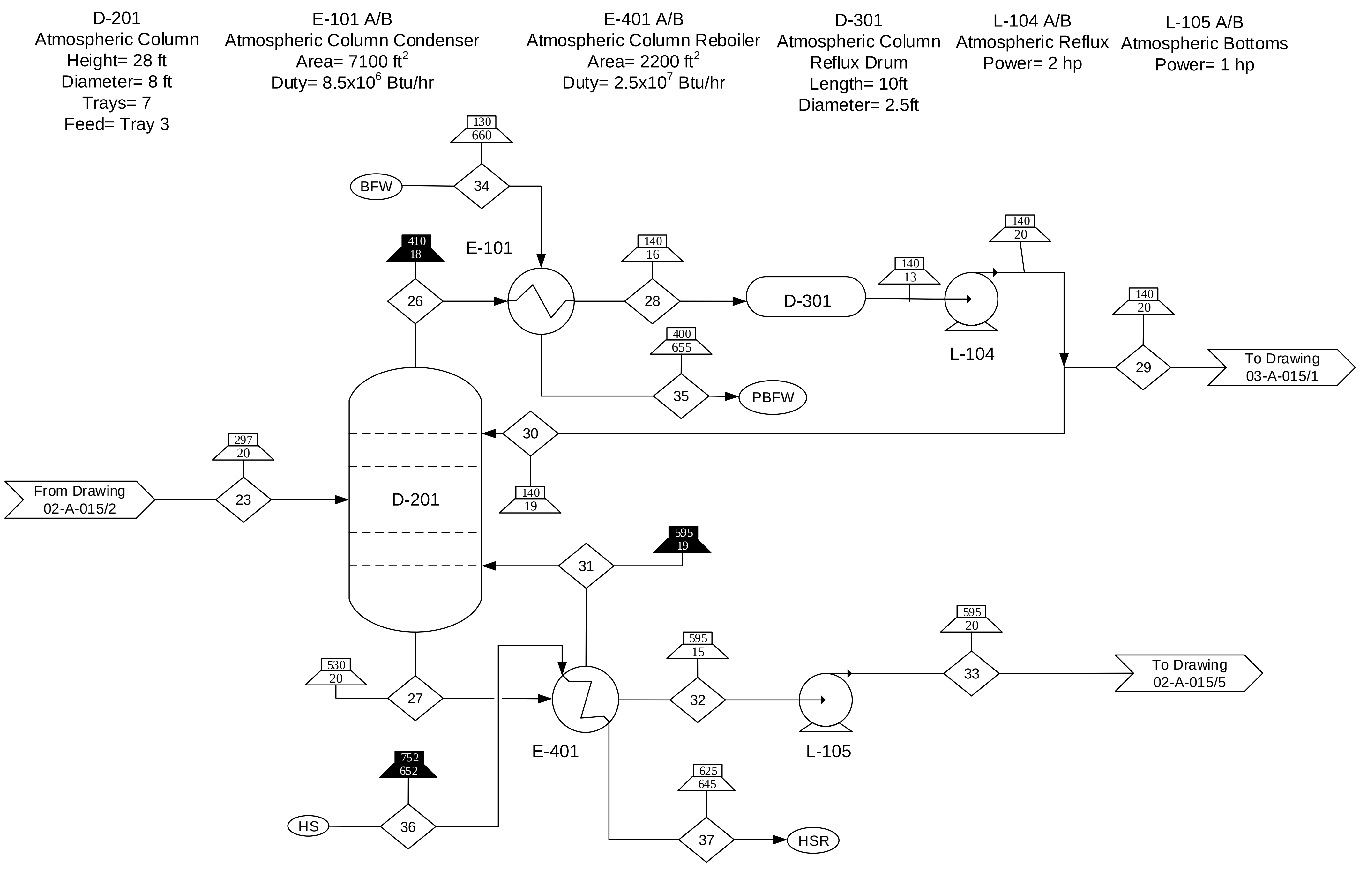
Reference Drawings:

Input/Output Diagram
00-A-013
Block Flow Diagram
00-A-014
Process Flow Diagrams
02-A-015
03-A-015
05-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	02-A-015/3	0



Component/Stream (lb/min)	23	26	27	28	29	30	31	32	33	34	35	36	37
C7-C12	0	400	0	400	370	30	0	0	0	0	0	0	0
C7-C50	1700	0	3200	0	0	0	1900	0	0	0	0	0	0
C13-C50	0	0	0	0	0	0	0	1300	1300	0	0	0	0
Water	0	0	0	0	0	0	0	0	0	170	170	5600	5600
Total	1700	400	3200	400	370	30	1900	1300	1300	170	170	5600	5600

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
HS High Pressure Steam
HSR High Pressure Steam Recycle
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-013
Block Flow Diagram
00-A-014
Process Flow Diagrams
02-A-015
03-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	02-A-015/4	0

D-202
Vacuum Column
Height= 67 ft
Diameter= 9.5 ft
Trays= 20
Feed= Tray 5

E-102 A/B
Vacuum Column Condenser
Area= 600 ft^2
Duty= $1.9x10^7$ Btu/hr

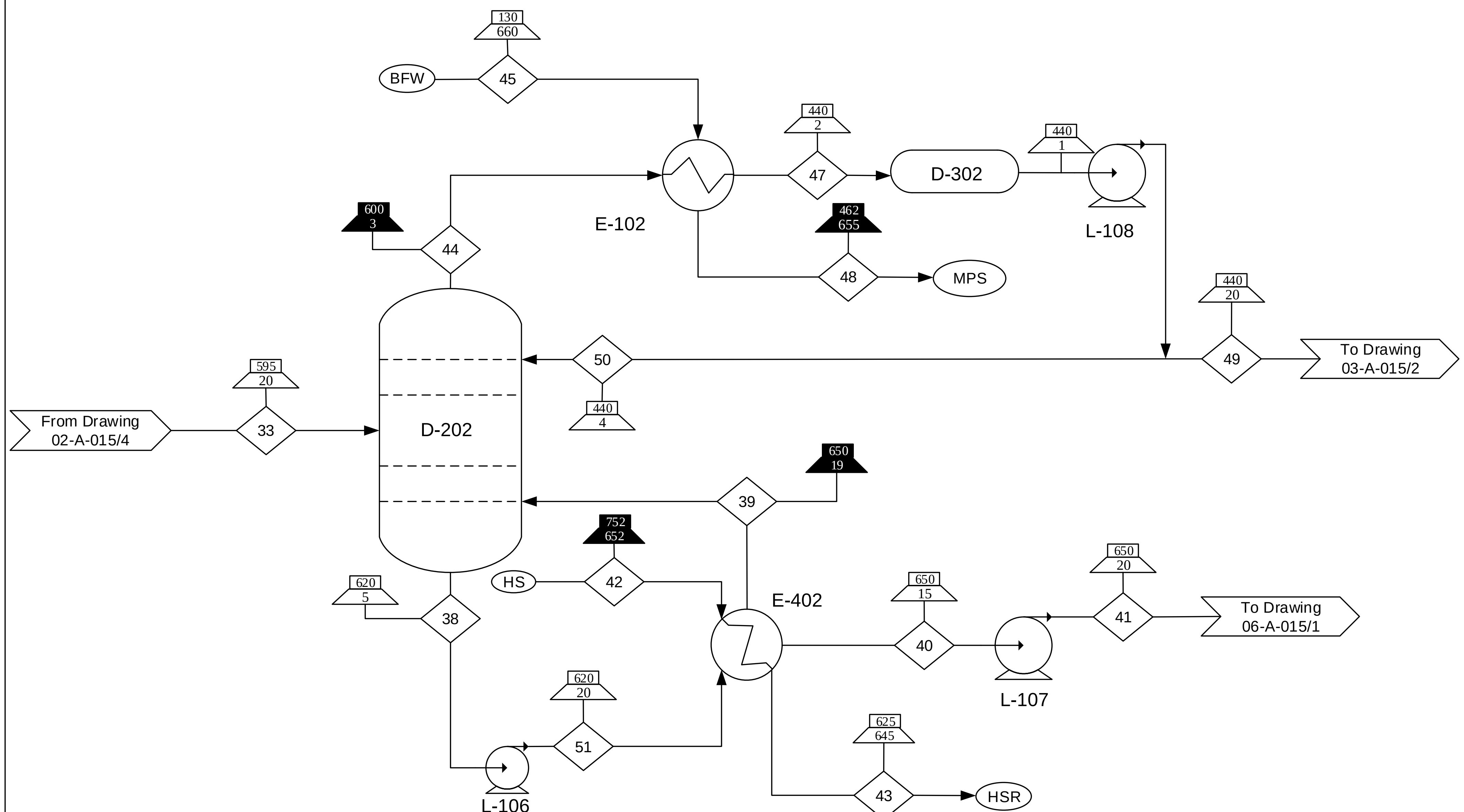
E-402 A/B
Vacuum Column Reboiler
Area= 9030 ft^2
Duty= $1.5x10^7$ Btu/hr

D-302
Vacuum Column Reflux Drum
Length= 18 ft
Diameter= 4.5 ft

L-106 A/B
Vacuum Column Bottoms
Power= 6 hp

L-107 A/B
Vacuum Bottoms
Power= 1 hp

L-108 A/B
Vacuum Reflux
Power= 7 hp



Component/Stream (lb/min)	33	38	39	40	41	42	43	44	45	46	47	48	49	50	51
C12-C50	1300	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C12-C30	0	0	0	0	0	0	0	1700	0	1700	1700	0	700	950	0
C30-C50	0	2200	1600	2200	620	0	0	0	0	0	0	0	0	0	2200
Water	0	0	0	0	0	3300	3300	0	380	0	0	380	0	0	0
Total	1300	2200	1600	2200	620	3300	3300	1700	380	1700	1700	380	700	950	2200

Notes
1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature
Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
HS High Pressure Steam
HSR High Pressure Steam Recycle
BFW Boiler Feed Water
MPS Medium Pressure Steam

Reference Drawings:
Input/Output Diagrams
00-A-013
Block Flow Diagrams
00-A-014
Process Flow Diagrams
02-A-015
03-A-015
06-A-015

Drawing Type
Process Flow Diagram

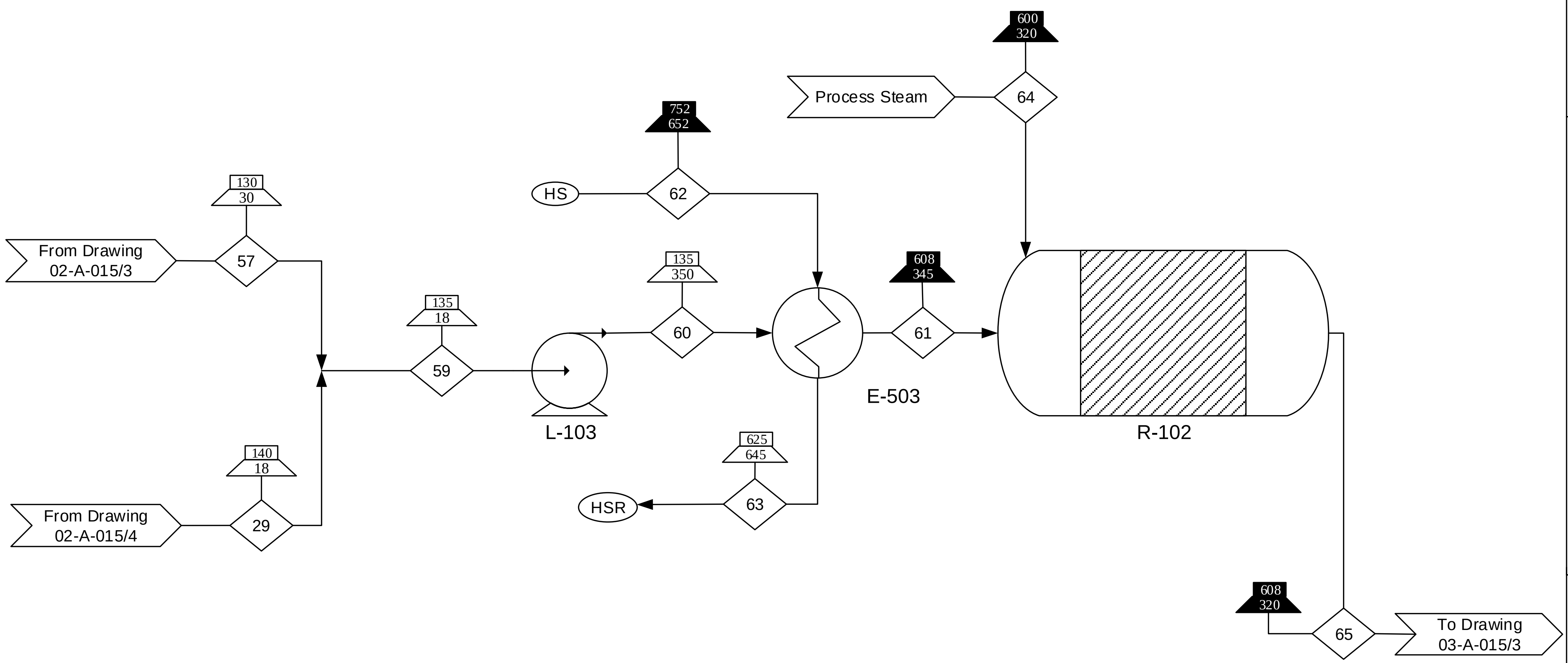
Title
Biorefinery Base Design with Mesophase Pitch- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	02-A-015/5	0

R-102 A/B
Naphtha Decarboxylation Reactor
Diameter= 9 ft
Length= 56 ft
Catalyst= 7700 ft^3

E-503 A/B
Naphtha Decarbox Heater
Area= 460 ft^2
Duty= $1.3x10^7$ Btu/hr

L-103 A/B
PreNaphtha Decarbox Pump
Power= 23 hp



Component/Stream (lb/min)	29	57	59	60	61	62	63	64	65
C6-C8	0	120	0	0	0	0	0	0	0
C7-C12	370	0	0	0	0	0	0	0	0
C6-C12	0	0	490	490	490	0	0	0	0
C1-C12	0	0	0	0	0	0	0	0	510
Water	0	0	0	0	0	2800	2800	15	0
Total	370	120	490	490	490	2800	2800	15	510

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in lb/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°F) Indicator, Liquid/Solid

Pressure (psia) Indicator, Liquid/Solid

Temperature (°F) Indicator, Gas

Pressure (psia) Indicator, Gas

HS High Pressure Steam

HSR High Pressure Steam Recycle

Reference Drawings:

Input/Output Diagram
00-A-013
Block Flow Diagram
00-A-014
Process Flow Diagrams
02-A-015
03-A-015

Drawing Type
Process Flow Diagram

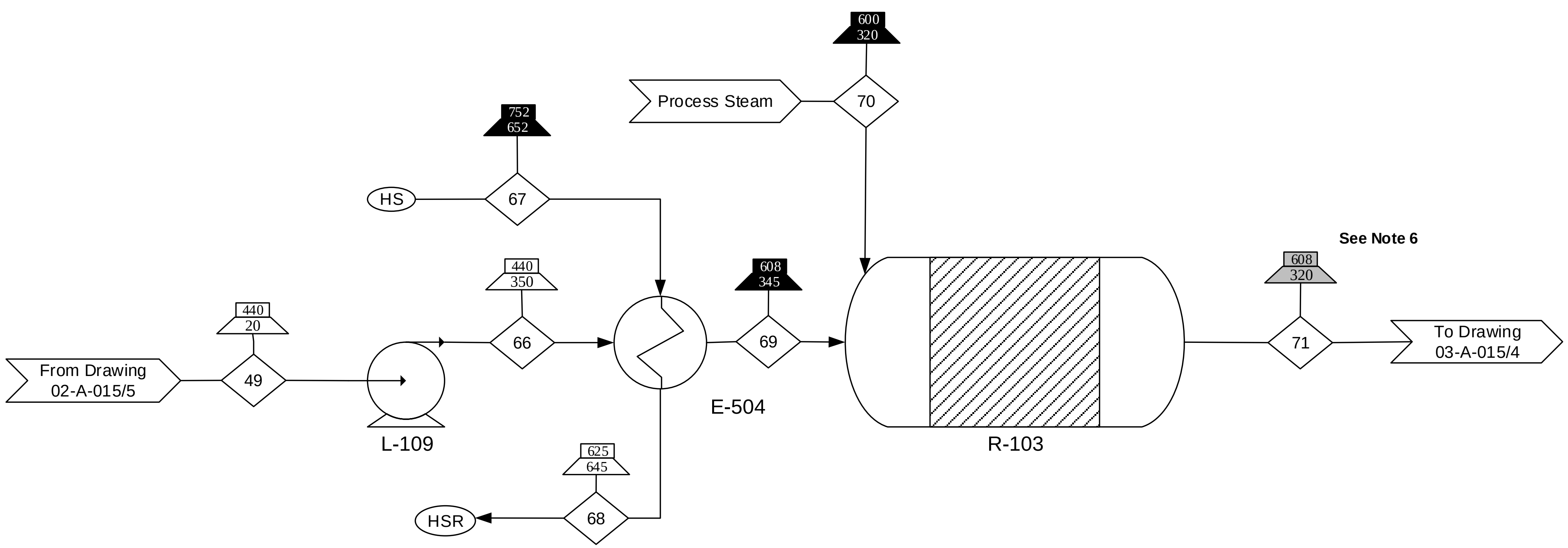
Title
Biorefinery Base Design with Mesophase Pitch – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	03-A-015/1	0

R-103 A/B
Diesel Decarboxylation Reactor
Diameter= 11 ft
Length= 63 ft
Catalyst= 11000 ft^3

E-504 A/B
Diesel Decarbox Heater
Area= 440 ft^2
Duty= 6.1×10^6 Btu/hr

L-109 A/B
Pre Diesel Decarbox Pump
Power= 39 hp



Component/Stream (lb/min)	49	66	67	68	69	70	71
C12-C30	700	700	0	0	700	0	0
C1-C30	0	0	0	0	0	0	720
Water	0	0	1400	1400	0	21	0
Total	700	700	1400	1400	700	21	720

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 71 is composed of a liquid gas two phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
HS High Pressure Steam
HSR High Pressure Steam Recycle

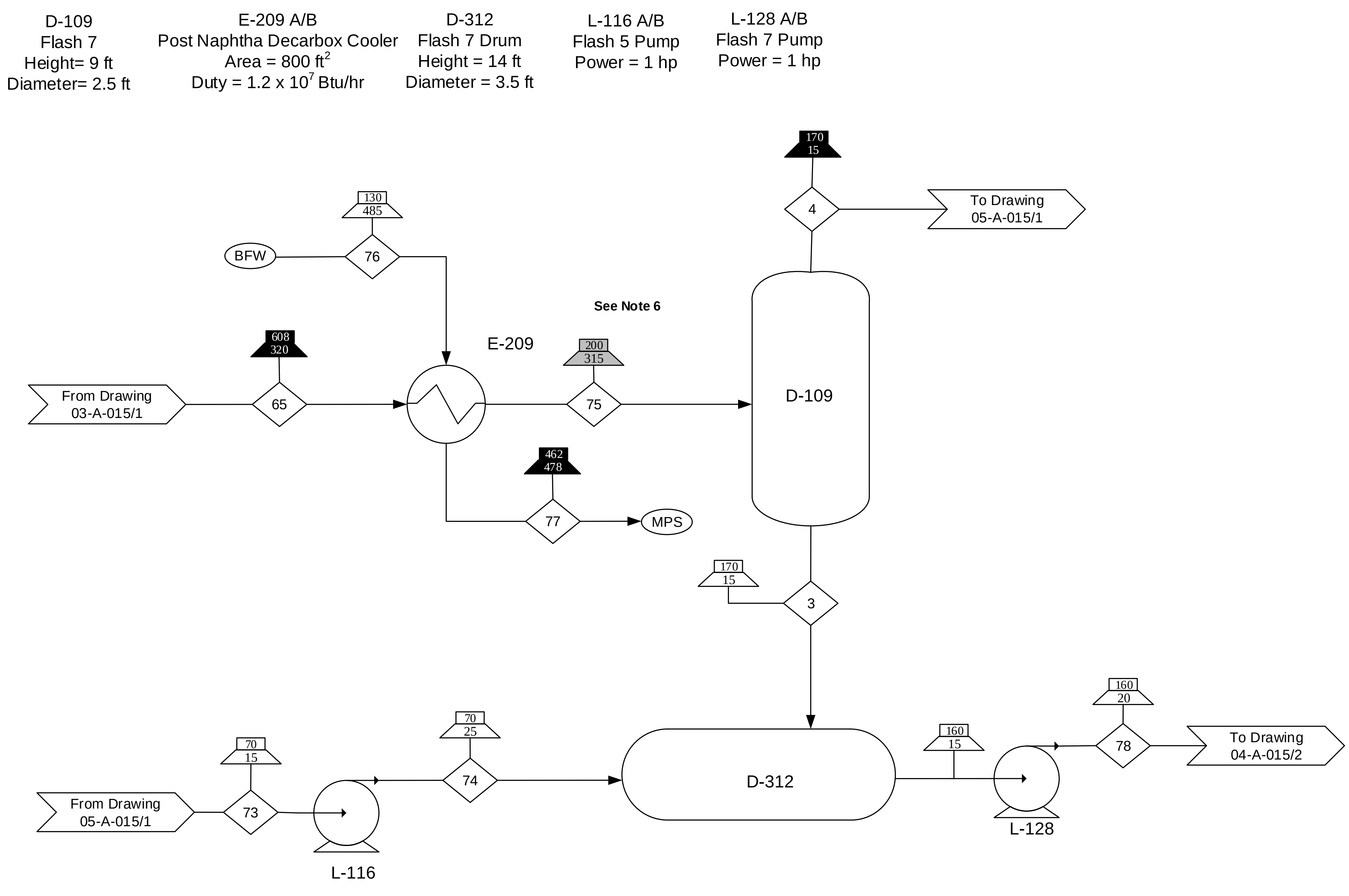
Reference Drawings:

Input/Output Diagram
00-A-013
Block Flow Diagram
00-A-014
Process Flow Diagrams
02-A-015
03-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	03-A-015/2	0



Component/Stream (lb/min)	65	73	74	75	76	77	3	4	78
C1-C12	510	0	0	510	0	0	0	0	0
C6-C9	0	50	50	0	0	0	0	0	440
C1-C4	0	0	0	0	0	0	0	120	0
C4-C12	0	0	0	0	0	0	390	0	0
Water	0	0	0	0	200	200	0	0	0
Total	510	50	50	510	200	200	390	120	440

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 75 is composed of a liquid and gas two phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
MPS Medium Pressure Steam
BFW Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-013
Block Flow Diagram
00-A-014
Process Flow Diagrams
03-A-015
04-A-015
05-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Decarboxylation Section

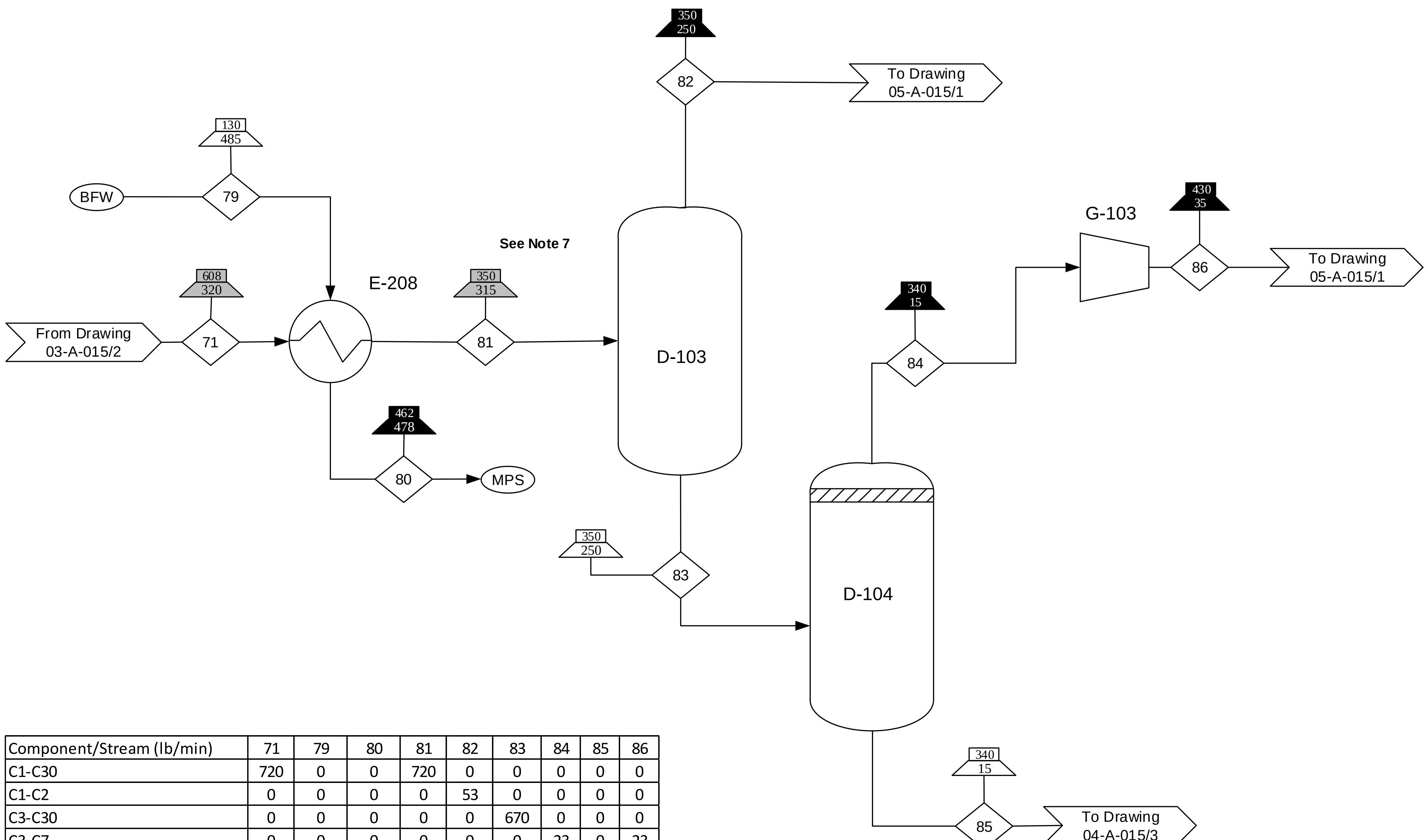
By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	03-A-015/3	0

D-103
Flash 3
Height= 16 ft
Diameter= 4 ft

D-104
Flash 4
Height= 15.5 ft
Diameter= 4 ft

E-208 A/B
Post Diesel Decarbox Cooler
Area= 350 ft^2
Duty= $9.6x10^6$ Btu/hr

G-103 A/B
Flash 5 Compressor
Power= 20 hp



Component/Stream (lb/min)	71	79	80	81	82	83	84	85	86
C1-C30	720	0	0	720	0	0	0	0	0
C1-C2	0	0	0	0	53	0	0	0	0
C3-C30	0	0	0	0	0	670	0	0	0
C3-C7	0	0	0	0	0	0	23	0	23
C8-C30	0	0	0	0	0	0	0	640	0
Water	0	150	150	0	0	0	0	0	0
Total	720	150	150	720	53	670	23	640	23

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
7. Streams 71 and 81 are composed of a liquid and gas two phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
MPS Medium Pressure Steam
BFW Boiler Feed Water

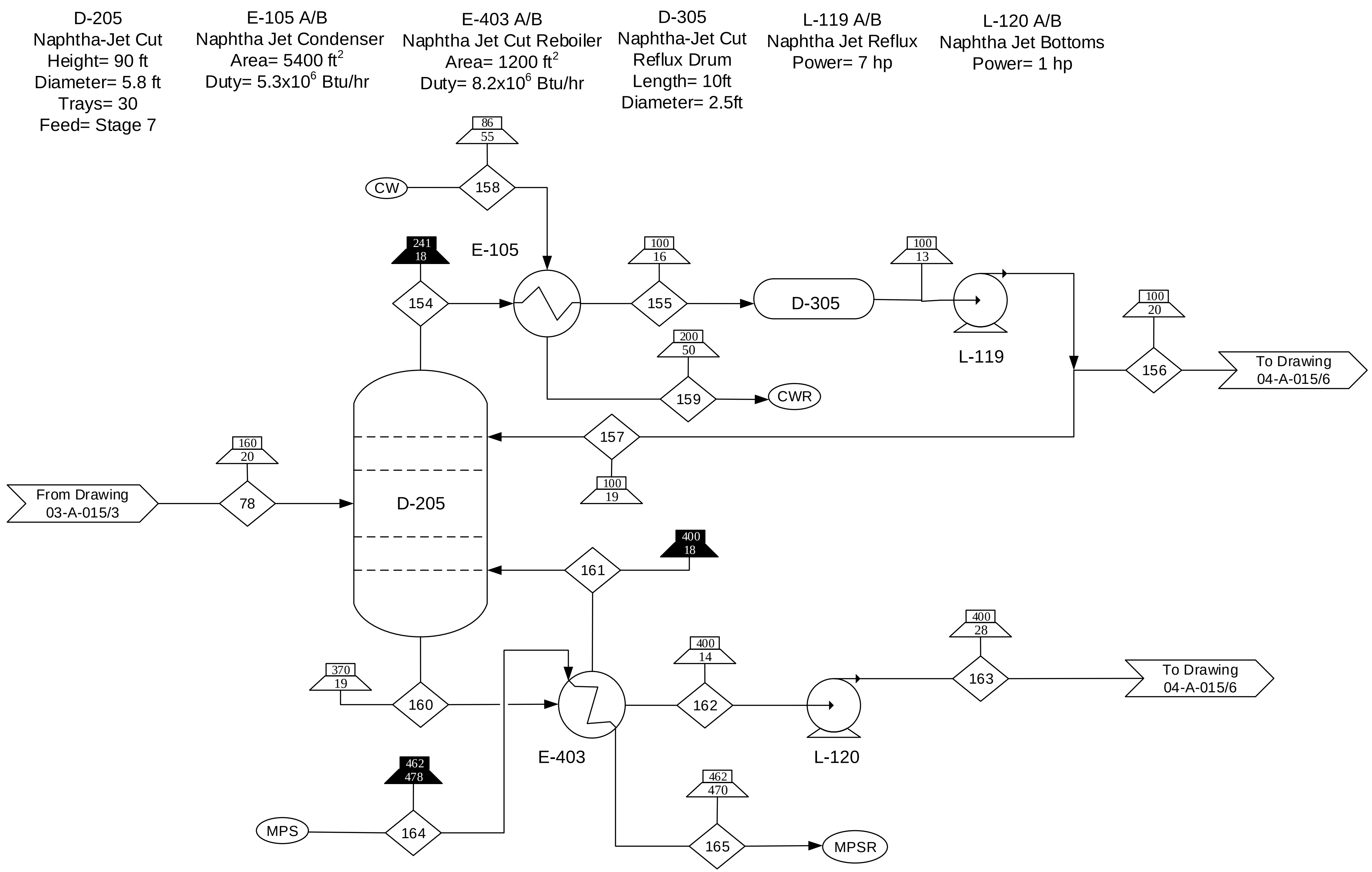
Reference Drawings:

Process Flow Diagrams
03-A-015
04-A-015
05-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	03-A-015/4	0



Component/Stream (lb/min)	78	154	155	156	157	158	159	160	161	162	163	164	165
C7-C12	440	0	0	0	0	0	0	0	0	0	0	0	0
C7-C9	0	320	320	140	180	0	0	0	0	0	0	0	0
C9-C12	0	0	0	0	0	0	0	720	420	300	300	0	0
Water	0	0	0	0	0	320	320	0	0	0	0	180	180
Total	440	320	320	140	180	320	320	720	420	300	300	180	180

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

- Stream Indicator
- Input/Output
- Temperature (°F) Indicator, Liquid/Solid
- Pressure (psia) Indicator, Liquid/Solid
- Temperature (°F) Indicator, Gas
- Pressure (psia) Indicator, Gas
- MPS — Medium Pressure Steam
- MPSR — Medium Pressure Steam Recycle
- CW — Cooling Water
- CWR — Cooling Water Recycle

Reference Drawings:

Input/Output Diagram
00-A-013
Block Flow Diagram
00-A-014
Process Flow Diagrams
03-A-015
04-A-015

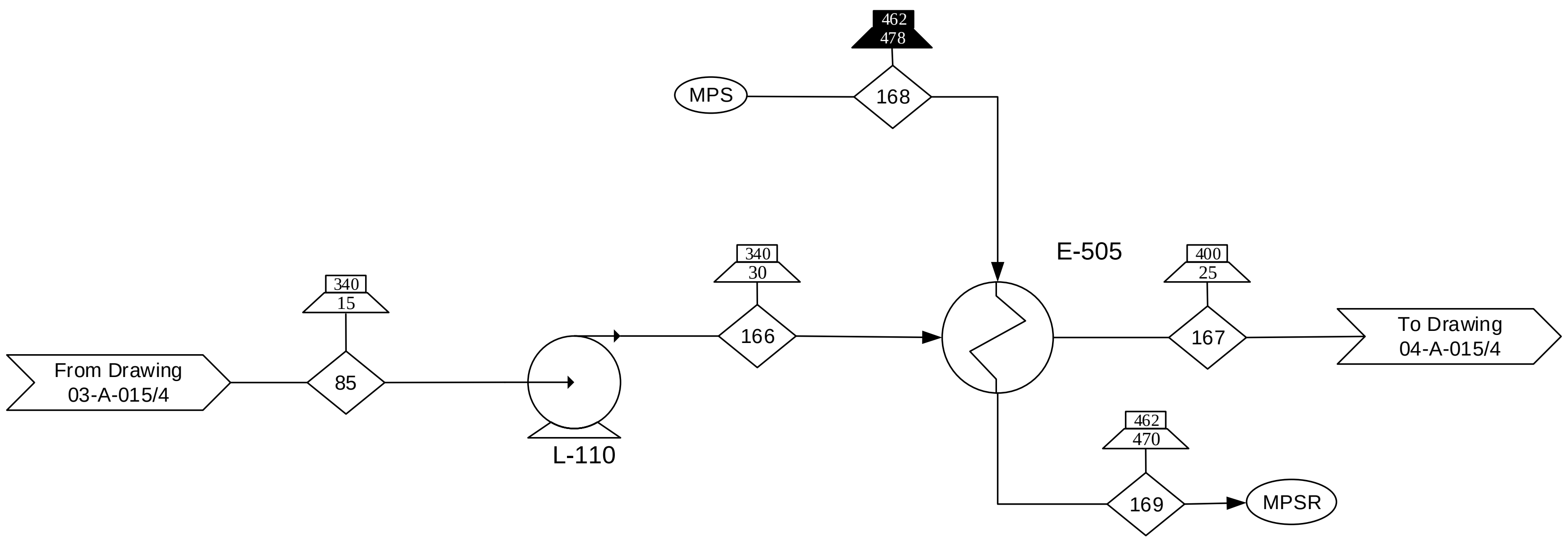
Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	04-A-015/2	0

E-505 A/B
Pre Jet Diesel Cut Heat
Area = 240 ft^2
Duty = 1.8 x 10^6 Btu/hr

L-110 A/B
Pre Jet Diesel Cut Heat Pump
Power = 2 hp

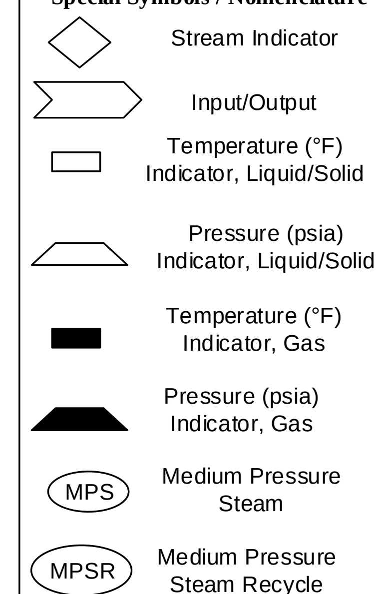


Component/Stream (lb/min)	85	166	167	168	169
C8-C30	640	640	640	0	0
Water	0	0	0	40	40
Total	640	640	640	40	40

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams

Special Symbols / Nomenclature



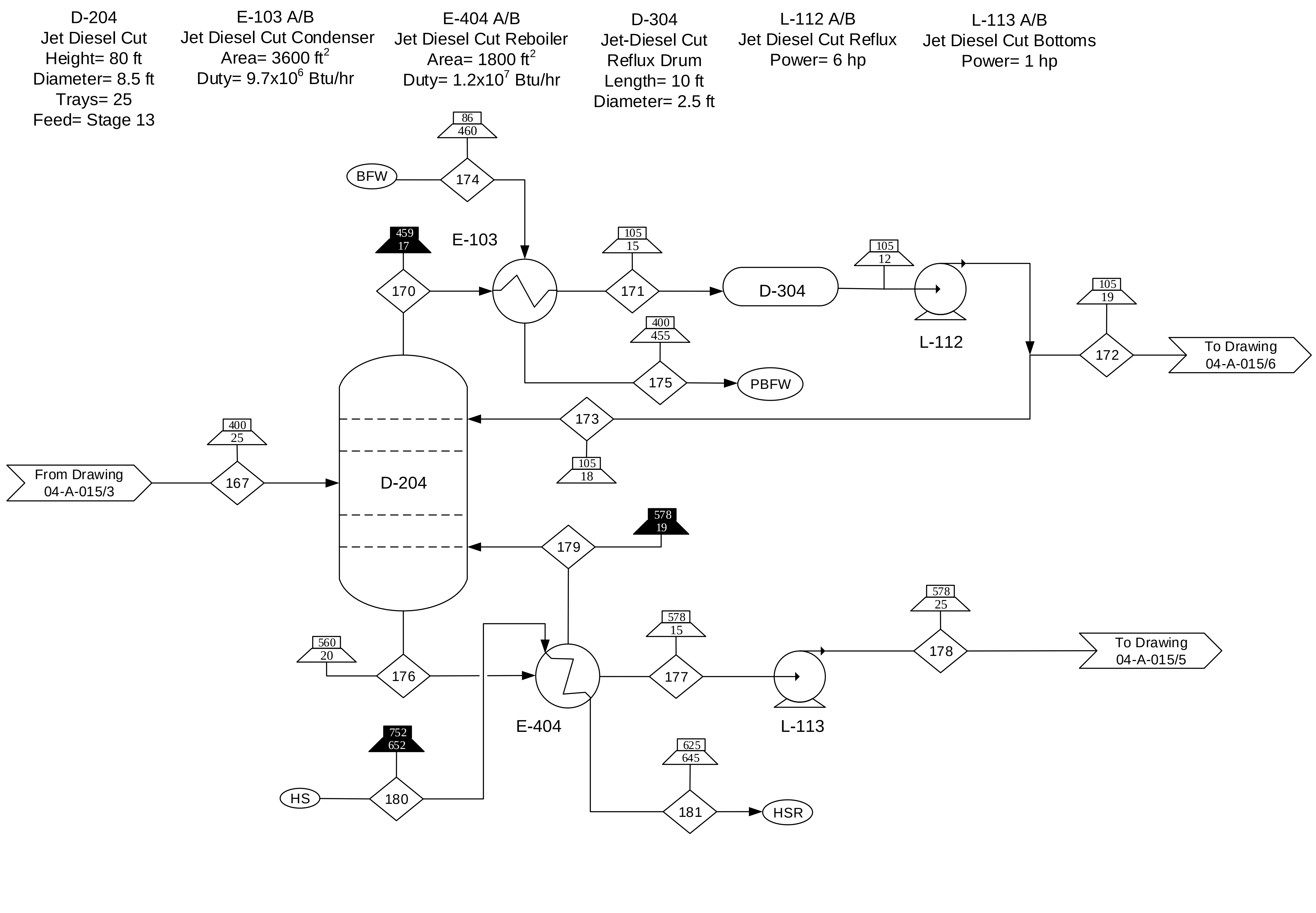
Reference Drawings:

Input/Output Diagram
00-A-013
Block Flow Diagram
00-A-014
Process Flow Diagrams
03-A-015
04-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	04-A-015/3	0

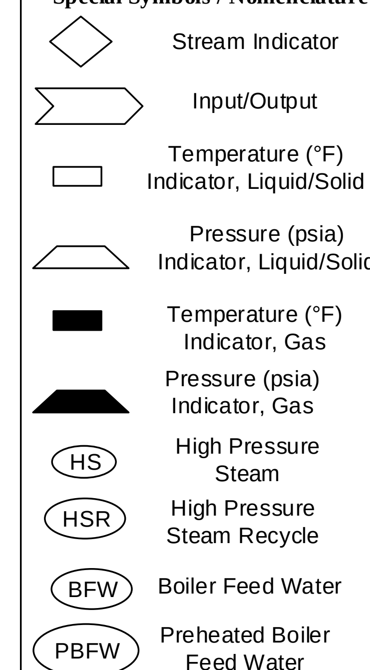


Component/Stream (lb/min)	167	170	171	172	173	174	175	176	177	178	179	180	181
C8-C30	640	0	0	0	0	0	0	0	0	0	0	0	0
C8-C15	0	410	410	160	250	0	0	0	0	0	0	0	0
C16-C30	0	0	0	0	0	0	0	1900	480	480	1400	0	0
Water	0	0	0	0	0	200	200	0	0	0	0	2700	2700
Total	640	410	410	160	250	200	200	1900	480	480	1400	2700	2700

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



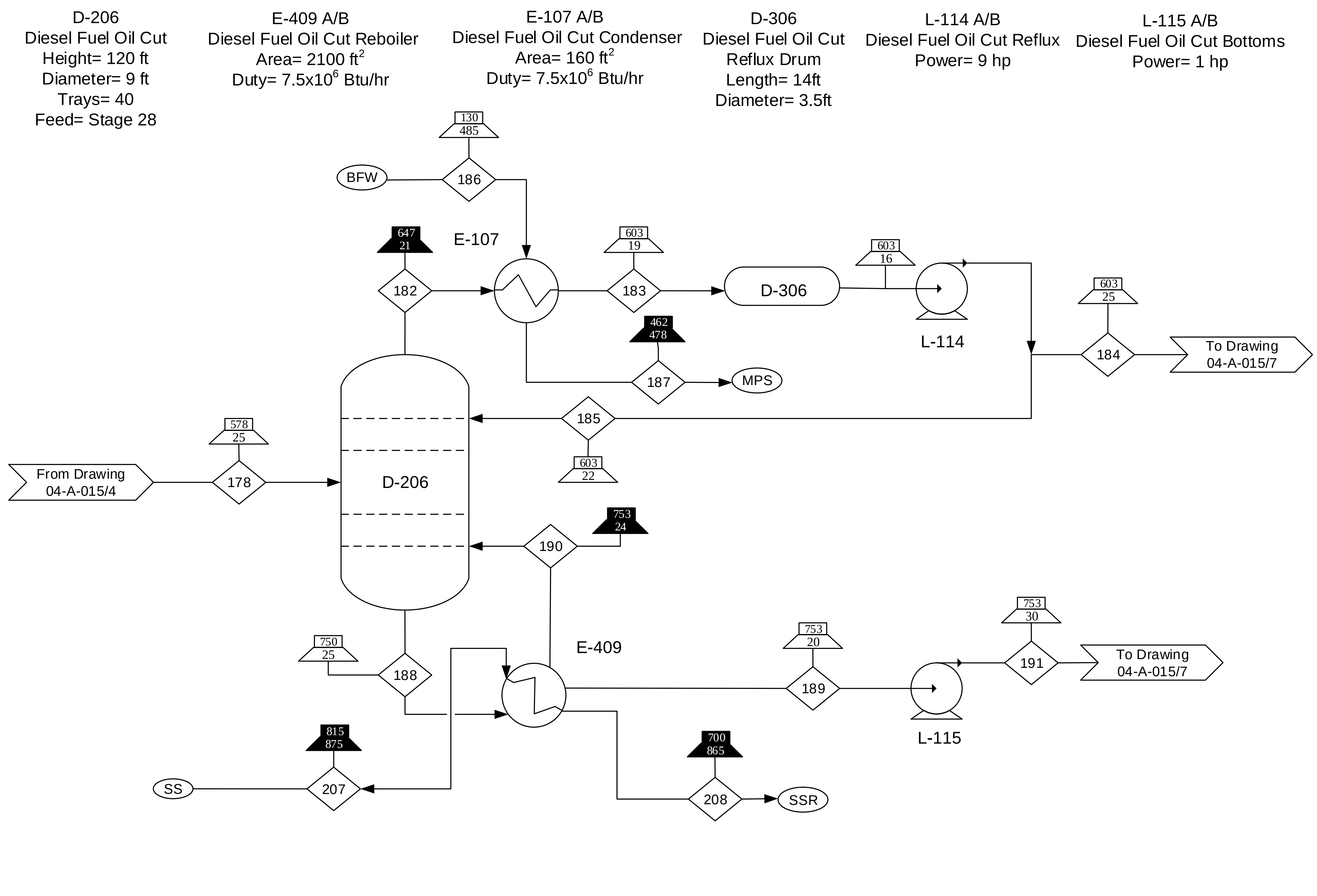
Reference Drawings:

Input/Output Diagam
00-A-013
Block Flow Diagram
00-A-014
Process Flow Diagrams
04-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	04-A-015/4	0

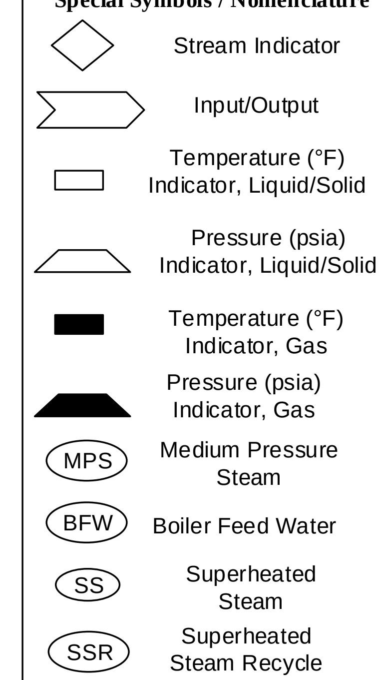


Component/Stream (lb/min)	178	182	183	184	185	186	187	188	189	190	191	207	208
C16-C30	480	0	0	0	0	0	0	0	0	0	0	0	0
C16-C21	0	830	830	470	360	0	0	0	0	0	0	0	0
C22-C30	0	0	0	0	0	0	0	1400	10	1400	9	0	0
Water	0	0	0	0	0	120	120	0	0	0	0	1700	1700
Total	480	830	830	470	360	120	120	1400	10	1400	9	1700	1700

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



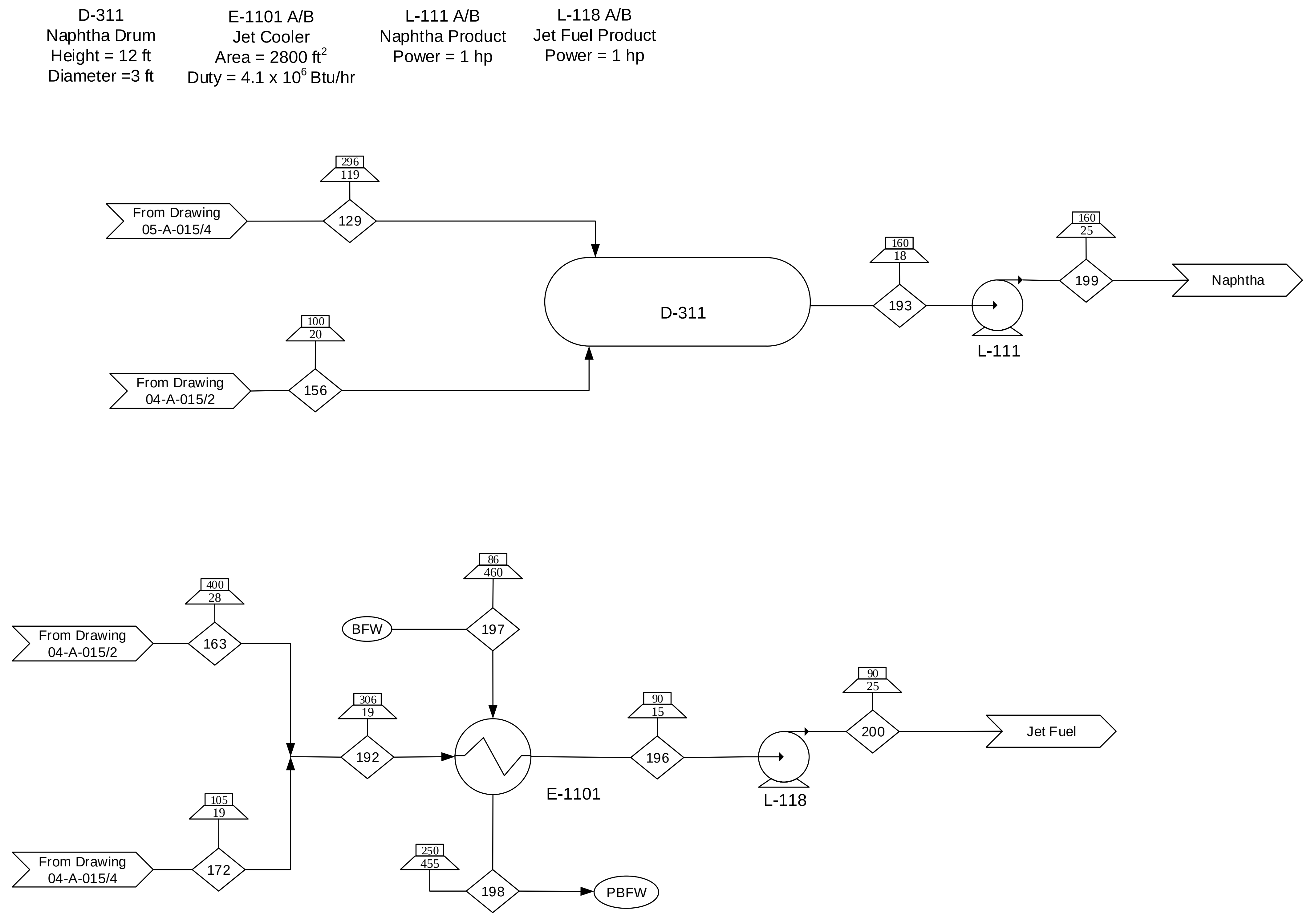
Reference Drawings:

Input/Output Diagram 00-A-013
Block Flow Diagram 00-A-014
Process Flow Diagrams 04-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	04-A-015/5	0

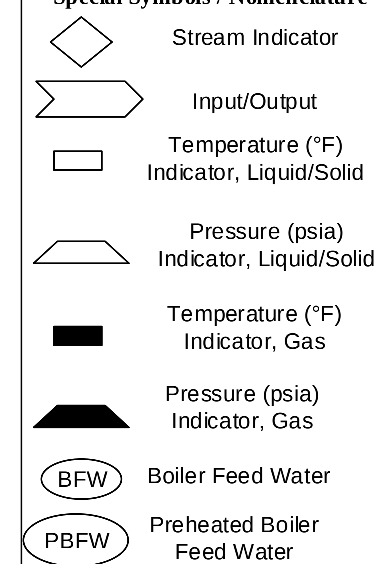


Component/Stream (lb/min)	129	156	163	172	192	193	196	197	198	199	200
Naphtha Product	140	140	0	0	0	280	0	0	0	280	0
Jet Fuel Product	0	0	300	160	470	0	470	0	0	0	470
Water	0	0	0	0	0	0	0	250	250	0	0
Total	140	140	300	160	470	280	470	250	250	280	470

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature



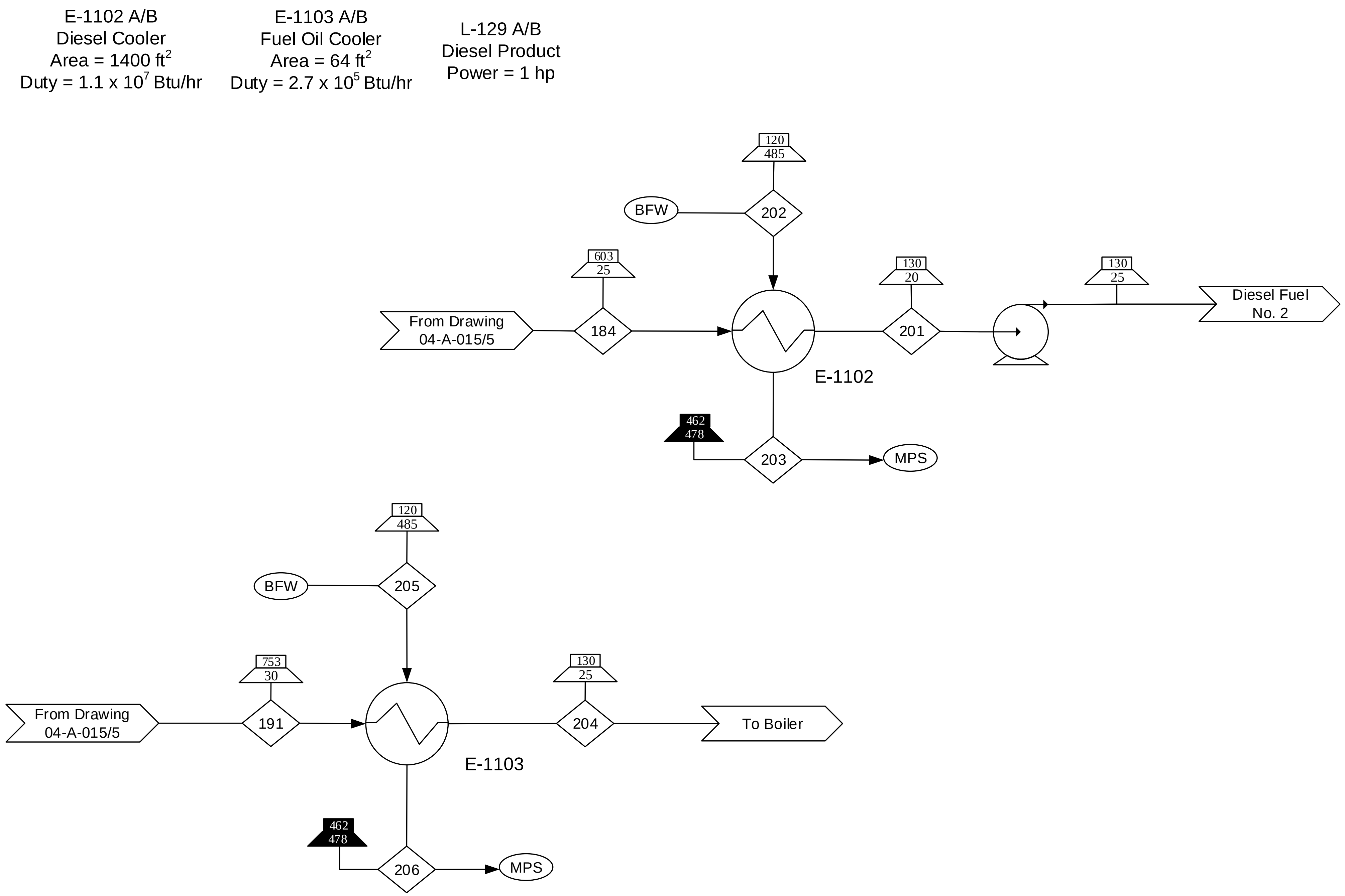
Reference Drawings:

Input/Output Diagram
00-A-013
Block Flow Diagram
00-A-014
Process Flow Diagrams
04-A-015
05-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	04-A-015/6	0



Component/Stream (lb/min)	184	191	201	202	203	204	205	206
Diesel Fuel No. 2 Product	470	0	470	0	0	0	0	0
Fuel Oil No. 5 Product	0	9	0	0	0	9	0	0
Water	0	0	0	160	160	0	5	5
Total	470	9	470	160	160	9	5	5

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
MPS Medium Pressure Steam
BFW Boiler Feed Water

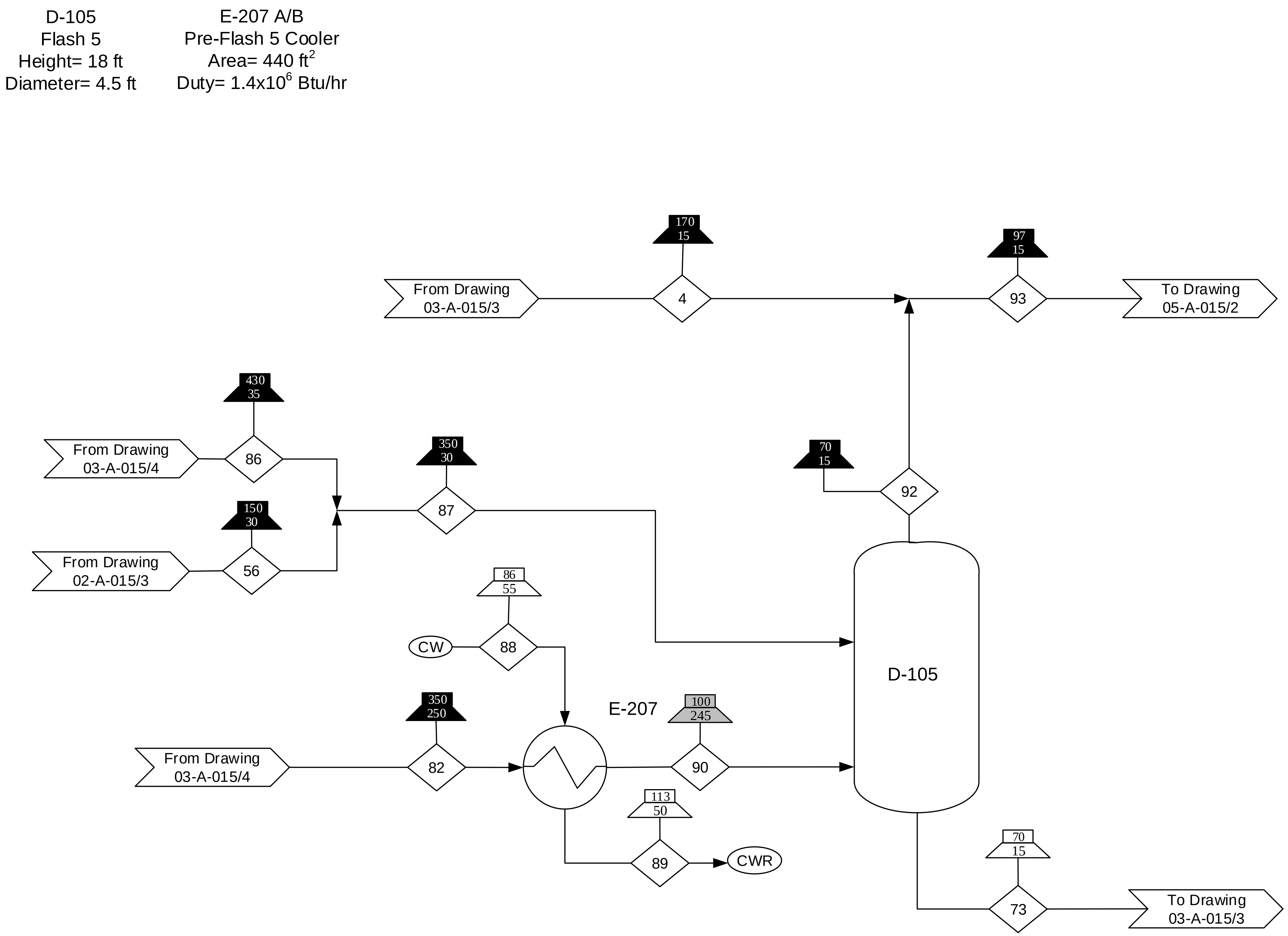
Reference Drawings:

Input/Output Diagram
00-A-013
Block Flow Diagram
00-A-014
Process Flow Diagrams
04-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	04-A-015/7	0



Component/Stream (lb/min)	4	56	73	82	86	87	88	89	90	92	93
C1-C2	0	0	0	53	0	0	0	0	53	0	0
C3-C7	0	0	0	0	23	0	0	0	0	0	0
C1-C7	0	0	0	0	0	0	0	0	0	0	0
C1-C6	120	380	0	0	0	400	0	0	0	410	530
C6-C7	0	0	50	0	0	0	0	0	0	0	0
Water	0	0	0	0	0	0	83	83	0	0	0
Total	120	380	50	53	23	400	83	83	53	410	530

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
CW Cooling Water
CWR Cooling Water Recycle

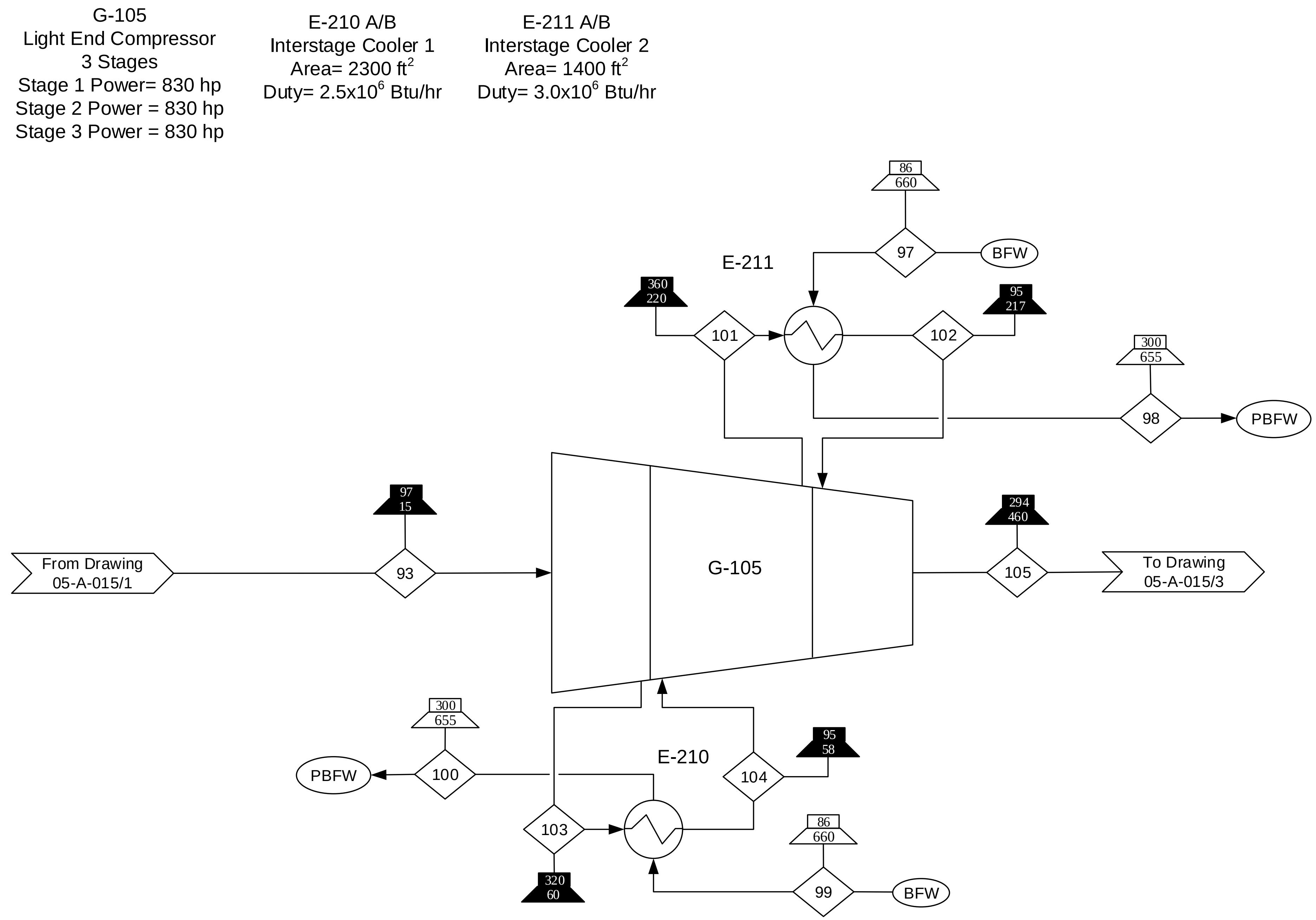
Reference Drawings:

Input/Output Diagram 00-A-013
Block Flow Diagram 00-A-014
Process Flow Diagrams 02-A-015 03-A-015 05-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	05-A-015/1	0



Component/Stream (lb/min)	93	97	98	99	100	101	102	103	104	105
C1-C6	530	0	0	0	0	530	530	530	530	530
Water	0	180	180	150	150	0	0	0	0	0
Total	530	180	180	150	150	530	530	530	530	530

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in lb/min.

4. Pumps operate at 65% efficiency.

5. Compressors operate at 55% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°F) Indicator, Liquid/Solid

Pressure (psia) Indicator, Liquid/Solid

Temperature (°F) Indicator, Gas

Pressure (psia) Indicator, Gas

BFW Boiler Feed Water

PBFW Preheated Boiler Feed Water

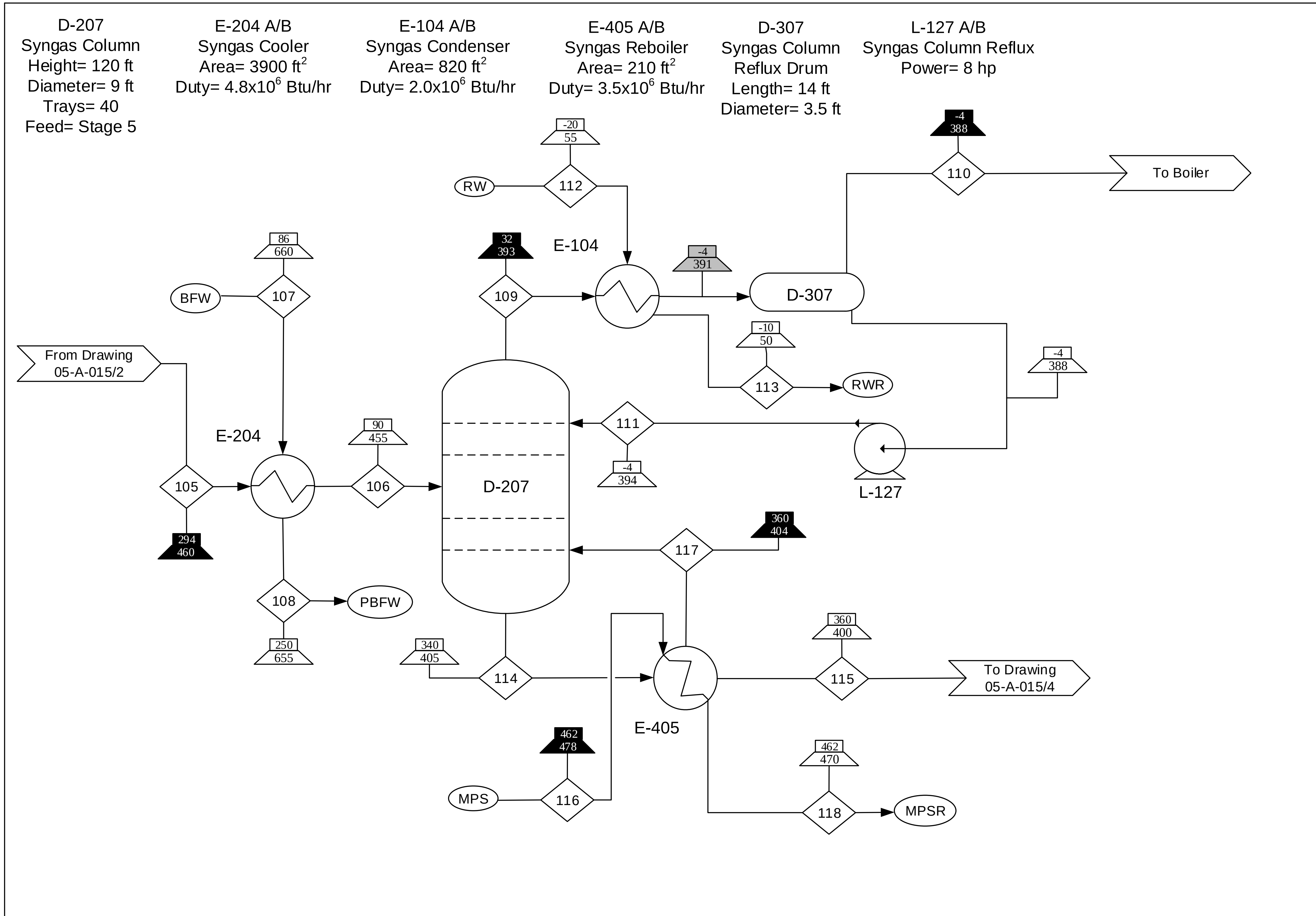
Reference Drawings:

Input/Output Diagram
00-A-013
Block Flow Diagram
00-A-014
Process Flow Diagrams
05-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	05-A-015/2	0



Component/Stream (lb/min)	105	106	107	108	109	110	111	112	113	114	115	116	117	118
C1-C6	530	540	0	0	0	0	0	0	0	0	0	0	0	0
C1-C3	0	0	0	0	520	350	170	0	0	0	0	0	0	0
C4-C6	0	0	0	0	0	0	0	0	0	770	180	0	590	0
Water	0	0	290	290	0	0	0	1200	1200	0	0	75	0	75
Total	530	540	290	290	520	350	170	1200	1200	770	180	75	590	75

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in lb/min.

4. Pumps operate at 65% efficiency.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

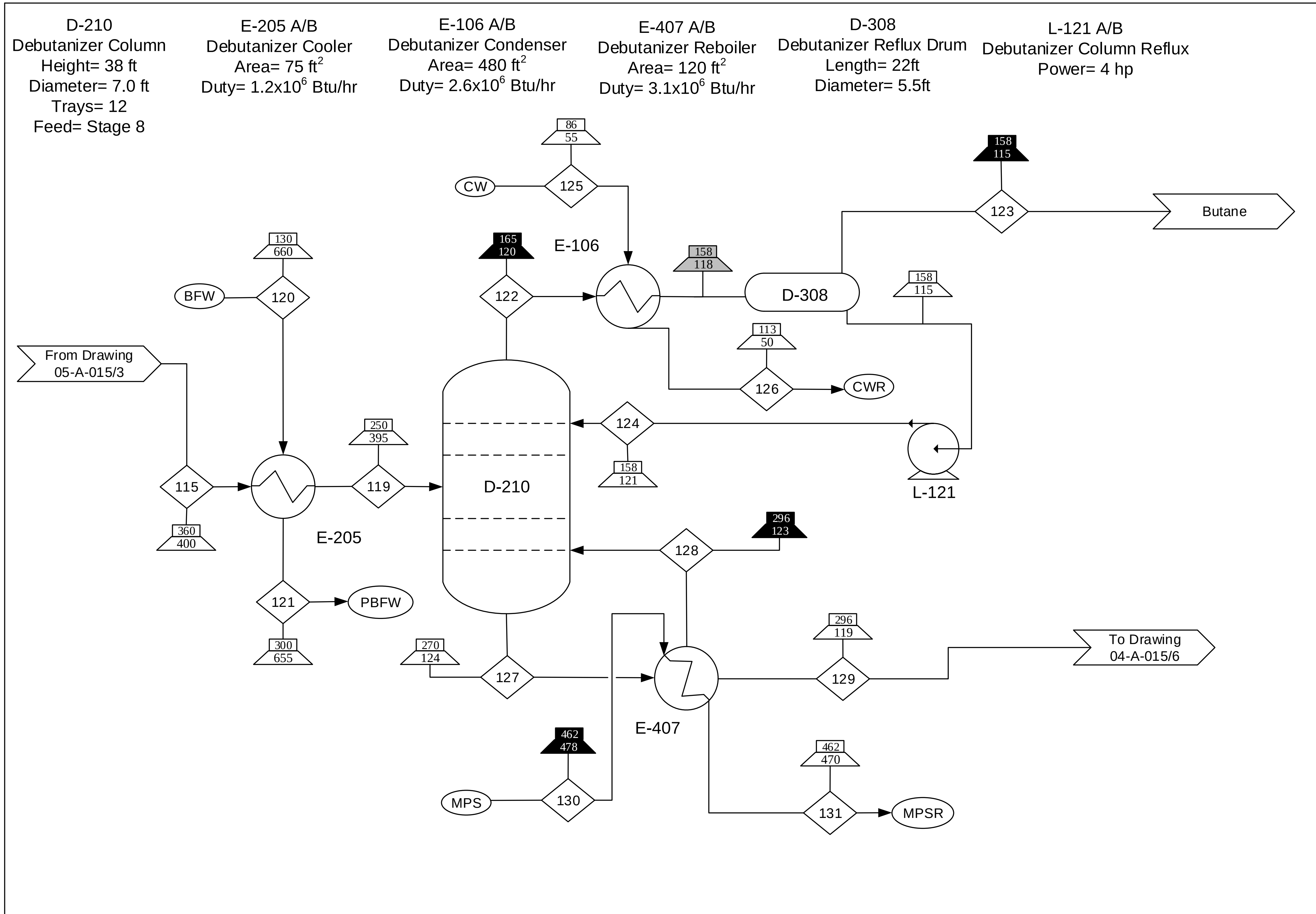
Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
MPS Medium Pressure Steam
MPSR Medium Pressure Steam Recycle
RW Refrigerated Water
RWR Refrigerated Water Recycle
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

Reference Drawings:
Input/Output Diagram
00-A-013
Block Flow Diagram
00-A-014
Process Flow Diagrams
05-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	05-A-015/3	0



Component/Stream (lb/min)	115	119	120	121	122	123	124	125	126	127	128	129	130	131
C4-C6	180	180	0	0	0	0	0	0	0	0	0	0	0	0
Butane	0	0	0	0	340	46	290	0	0	0	0	0	0	0
C5-C6	0	0	0	0	0	0	0	0	0	500	360	140	0	0
Water	0	0	71	71	0	0	0	160	160	0	0	0	68	68
Total	180	180	71	71	340	46	290	160	160	500	360	140	68	68

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
5. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
MPS Medium Pressure Steam
MPSR Medium Pressure Steam Recycle
CW Cooling Water
CWR Cooling Water Recycle
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram 00-A-013
Block Flow Diagram 00-A-014
Process Flow Diagrams 04-A-015, 05-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Light End Processing

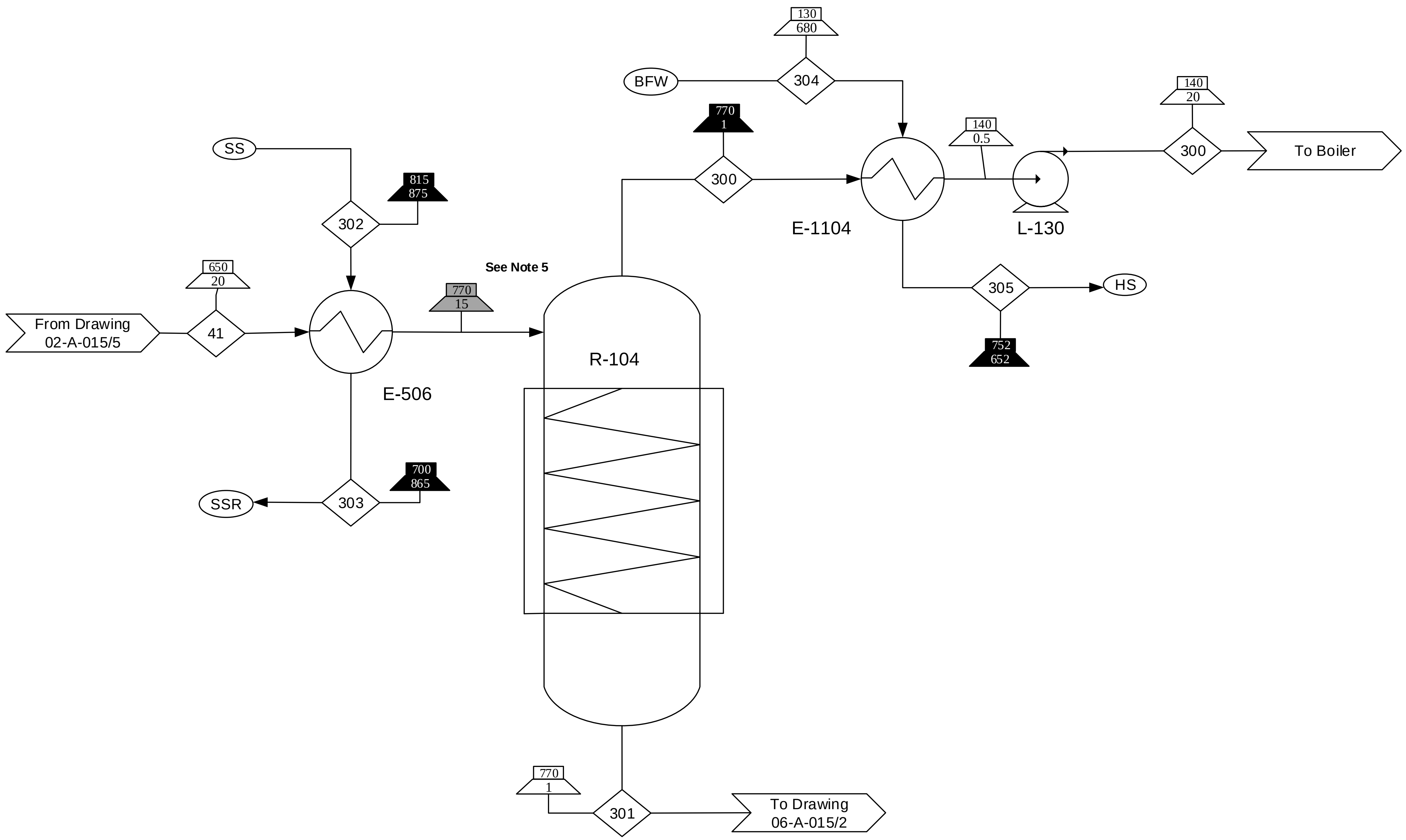
By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	05-A-015/4	0

R-104
Pitching Reactor
Height = 15 ft
Diameter = 5 ft
Power = 30 hp
Duty = 1.2×10^8 Btu/hr

E-1104 A/B
Fuel Oil Cooler 2
Area = 7400 ft^2
Duty = 1.5×10^7 Btu/hr

E-506 A/B
Pitching Preheat
Area = 1200 ft^2
Duty = 8.1×10^6 Btu/hr

L-130 A/B
Fuel Oil Pump
Power = 1 hp



Component/Stream (lb/min)	41	300	301	302	303	304	305
C30-C50	620	0	0	0	0	0	0
Fuel Oil No. 5 Product	0	400	0	0	0	0	0
Mesophase Pitch	0	0	220	0	0	0	0
Water	0	0	0	1800	1800	240	240
Total	620	400	220	1800	1800	240	240

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. Stream 41 goes into the pitching reactor as a gas and liquid two-phase stream.

Special Symbols / Nomenclature

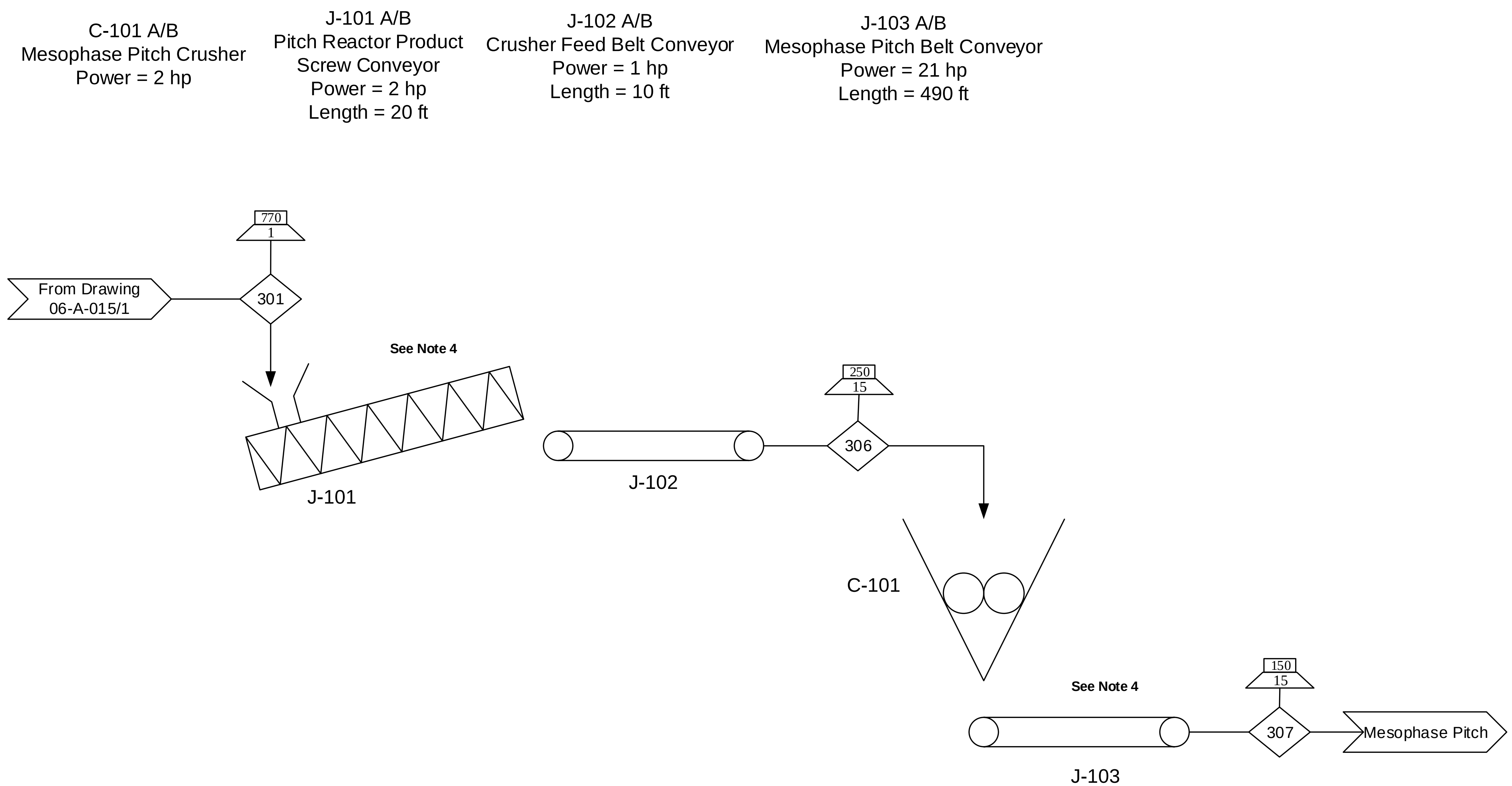
Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
HS High Pressure Steam
BFW Boiler Feed Water
SS Superheated Steam
SSR Superheated Steam Recycle

Reference Drawings:
Input/Output Diagram
00-A-013
Block Flow Diagram
00-A-014
Process Flow Diagrams
02-A-015
06-A-015

Drawing Type
Process Flow Diagram

Title
Biorefinery Base Design with Mesophase Pitch – Heavy End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	06-A-015/1	0



Component/Stream (lb/min)	301	306	307
Mesophase Pitch	220	220	220
Total	220	220	220

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Screw and conveyor are uninsulated, so pitch returns to ambient temperatures slowly.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°F) Indicator, Liquid/Solid

Pressure (psia) Indicator, Liquid/Solid

Reference Drawings:

Input/Output Diagram
00-A-013
Block Flow Diagram
00-A-014
Process Flow Diagrams
02-A-015
06-A-015

Drawing Type

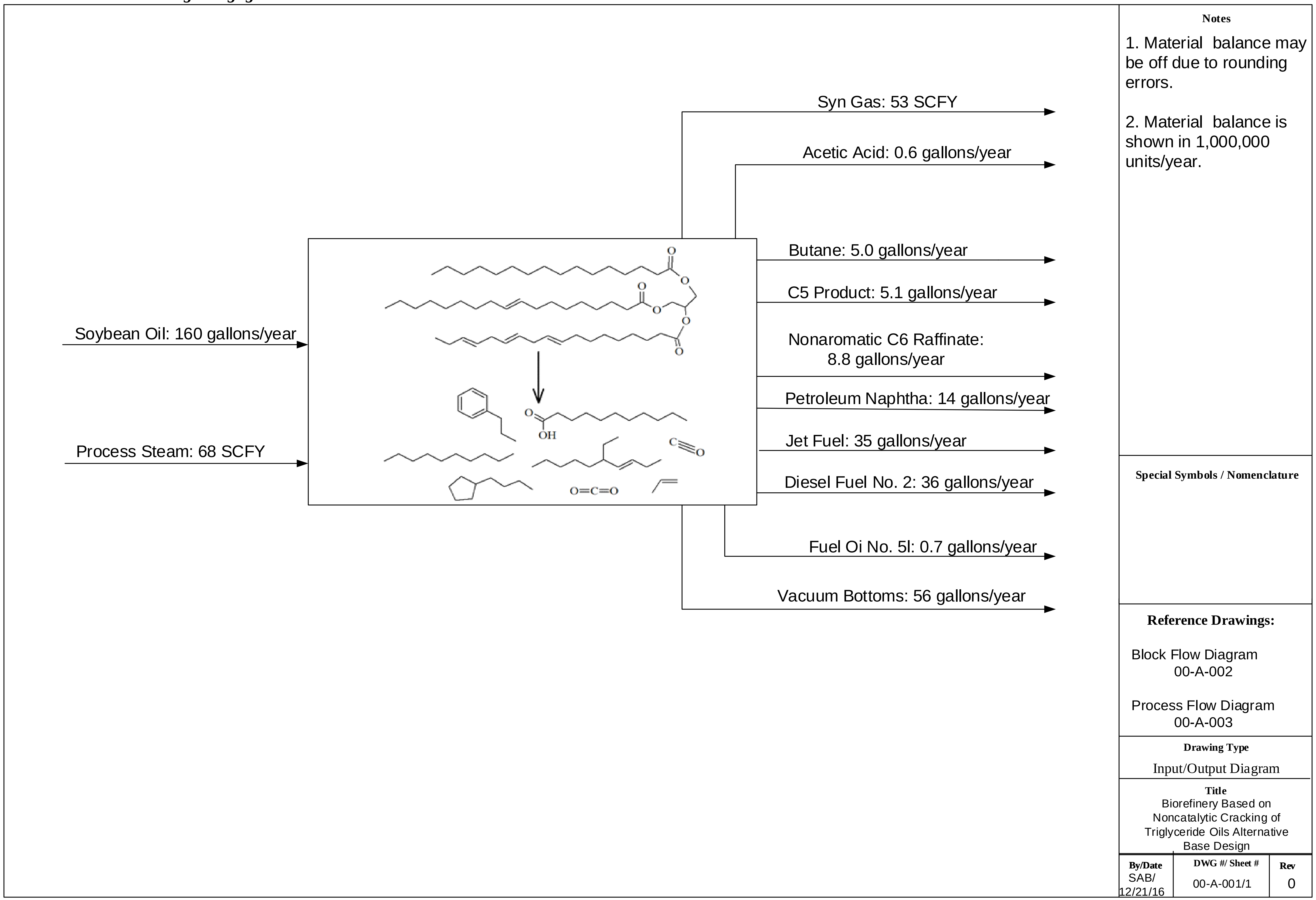
Process Flow Diagram

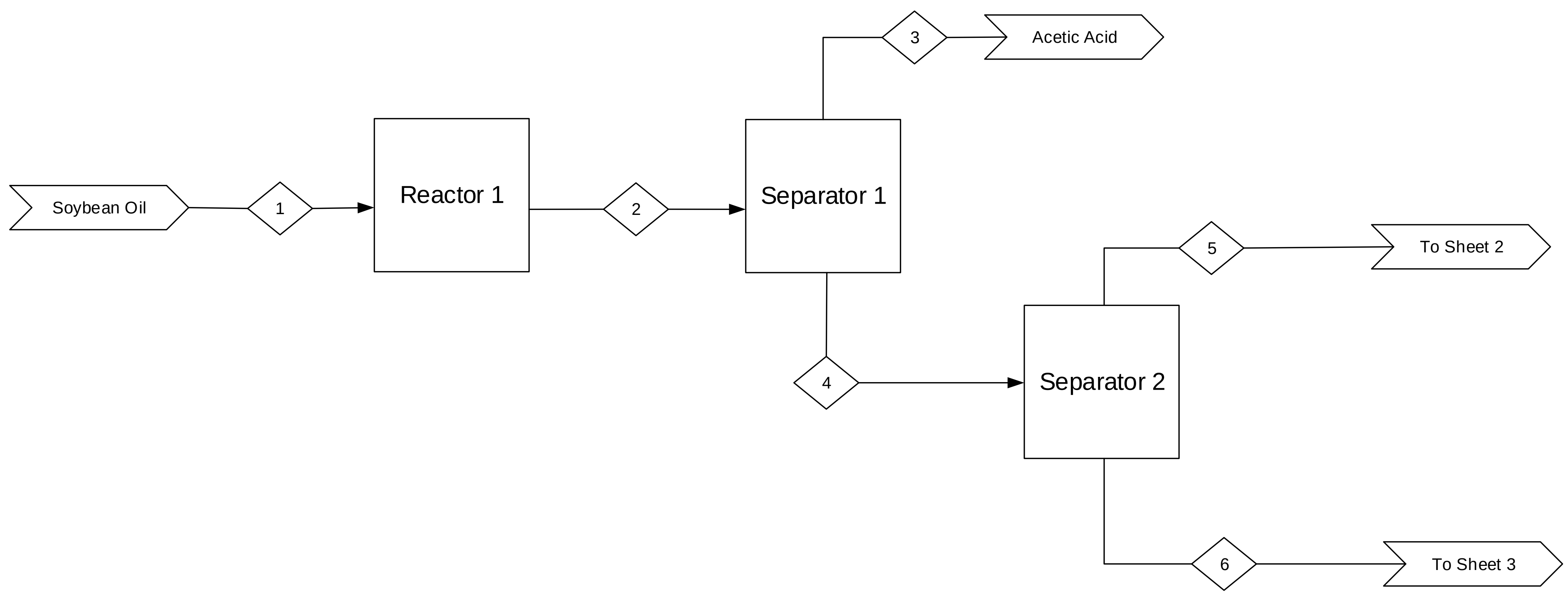
Title

Biorefinery Base Design with Mesophase Pitch – Heavy End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 4-4-17	06-A-015/2	0

I.4. Alternative Base Design Engligh Units





Component/Stream (lb/min)	1	2	3	4	5	6
Soybean Oil	2200	0	0	0	0	0
Acetic Acid	0	0	10	0	0	0
C1-C50	0	2200	0	2200	0	0
C1-C12	0	0	0	0	950	0
C12-C50	0	0	0	0	0	1200
Total	2200	2200	10	2200	950	1200

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 1: Crack incoming TG oil into fuel intermediates

Separator 1:Separate aqueous acetic acid from organic crackate

Separator 2: Separate the naphtha range fuel intermediates from the diesel range fuel intermediates

Special Symbols / Nomenclature

Input/Output

Stream Indicator

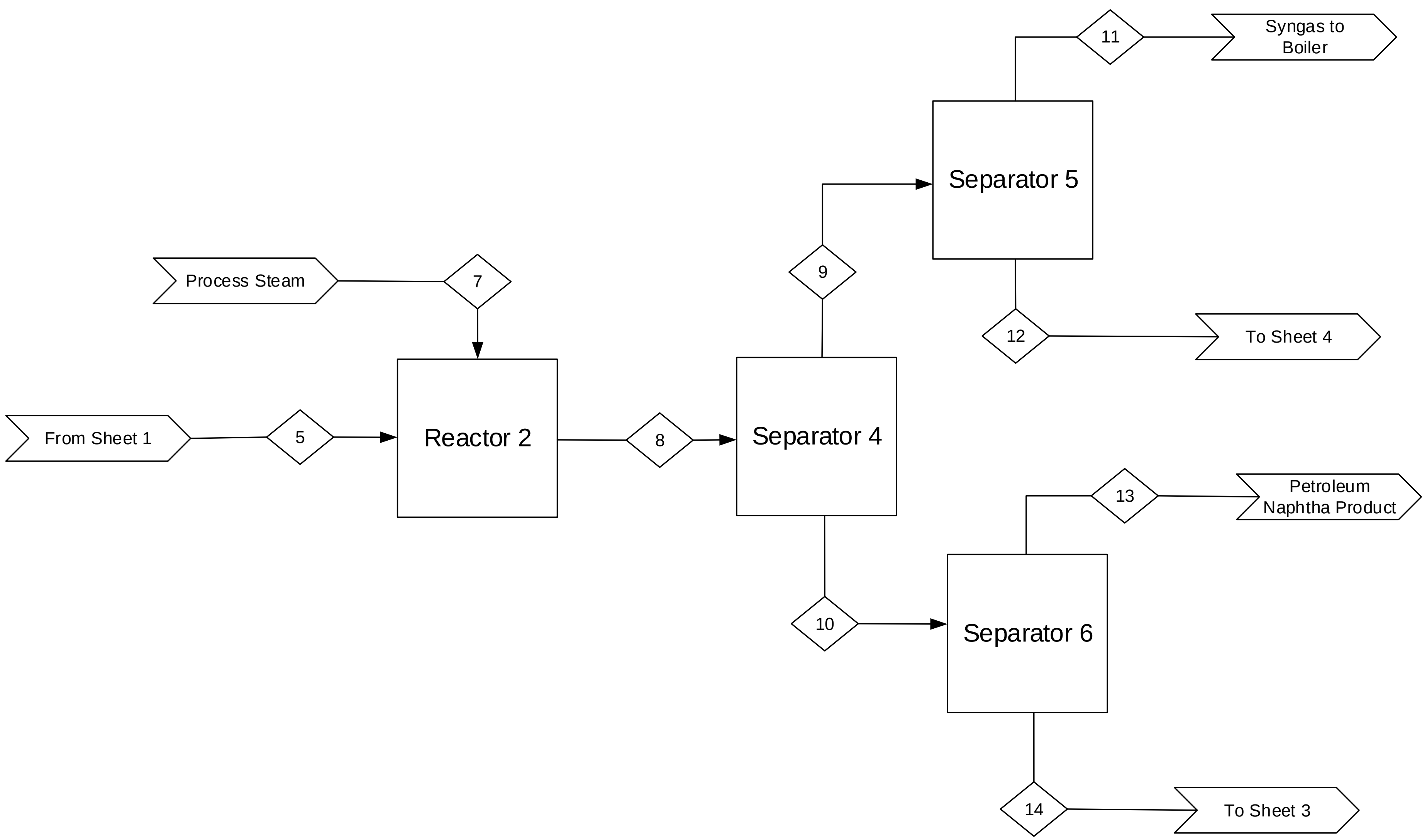
Reference Drawings:

Input/Output Diagram
00-A-001
Process Flow Diagram
00-A-003

Drawing Type
Block Flow Diagrams

Title
Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Alternative Base Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-21-16	00-A-002/1	0



Component/Stream (lb/min)	5	7	8	9	10	11	12	13	14
C1-C12	950	0	960	0	0	0	0	0	0
Steam	0	15	0	0	0	0	0	0	0
C1-C6	0	0	0	540	0	0	0	0	0
C1-C3	0	0	0	0	0	350	0	0	0
C4-C6	0	0	0	0	0	0	190	0	0
C7-C10	0	0	0	0	0	0	0	150	0
C11-C13	0	0	0	0	0	0	0	0	270
C7-C13	0	0	0	0	420	0	0	0	0
Total	950	15	960	540	420	350	190	150	270

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 2: Reacts the carboxylic acids and alkenes to produce hydrocarbons.

Separator 4: Removes light ends from naphtha range fuel intermediates.

Separator 5: Removes syngas from C4-C6 byproducts.

Separator 6: Separates petroleum naphtha product from jet fuel range fuel intermediates.

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram 00-A-001

Process Flow Diagram 00-A-003

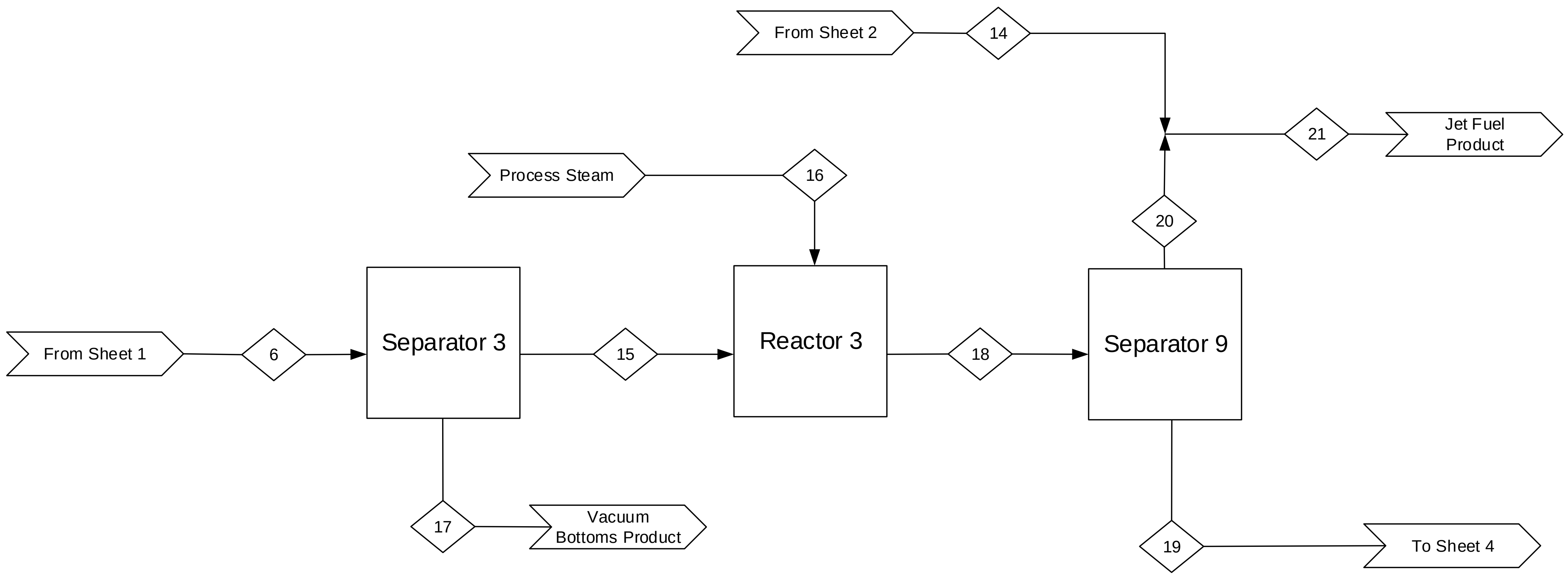
Drawing Type

Block Flow Diagram

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Alternative Base Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-21-16	00-A-002/2	0



Component/Stream (lb/min)	6	14	15	16	17	18	19	20	21
Steam	0	0	0	20	0	0	0	0	0
C12-C50	1200	0	0	0	0	0	0	0	0
C30-C50	0	0	0	0	620	0	0	0	0
C12-C30	0	0	620	0	0	640	0	0	0
C13-C15	0	0	0	0	0	0	0	160	0
C11-C13	0	270	0	0	0	0	0	0	0
C11-C15	0	0	0	0	0	0	0	0	440
C15-C30	0	0	0	0	0	0	480	0	0
Total	1200	270	620	20	620	640	480	160	440

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

6. Assume 100% separation in separators.

7. Reactor 3: Reacts carboxylic acids and alkenes to produce hydrocarbons.

Separator 3: Separates diesel fuel range intermediates from the vacuum bottoms byproduct.

Separator 9: Separates jet fuel range fuel intermediates from diesel fuel range intermediates.

Special Symbols / Nomenclature

Input/Output

Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-001

Process Flow Diagram
00-A-003

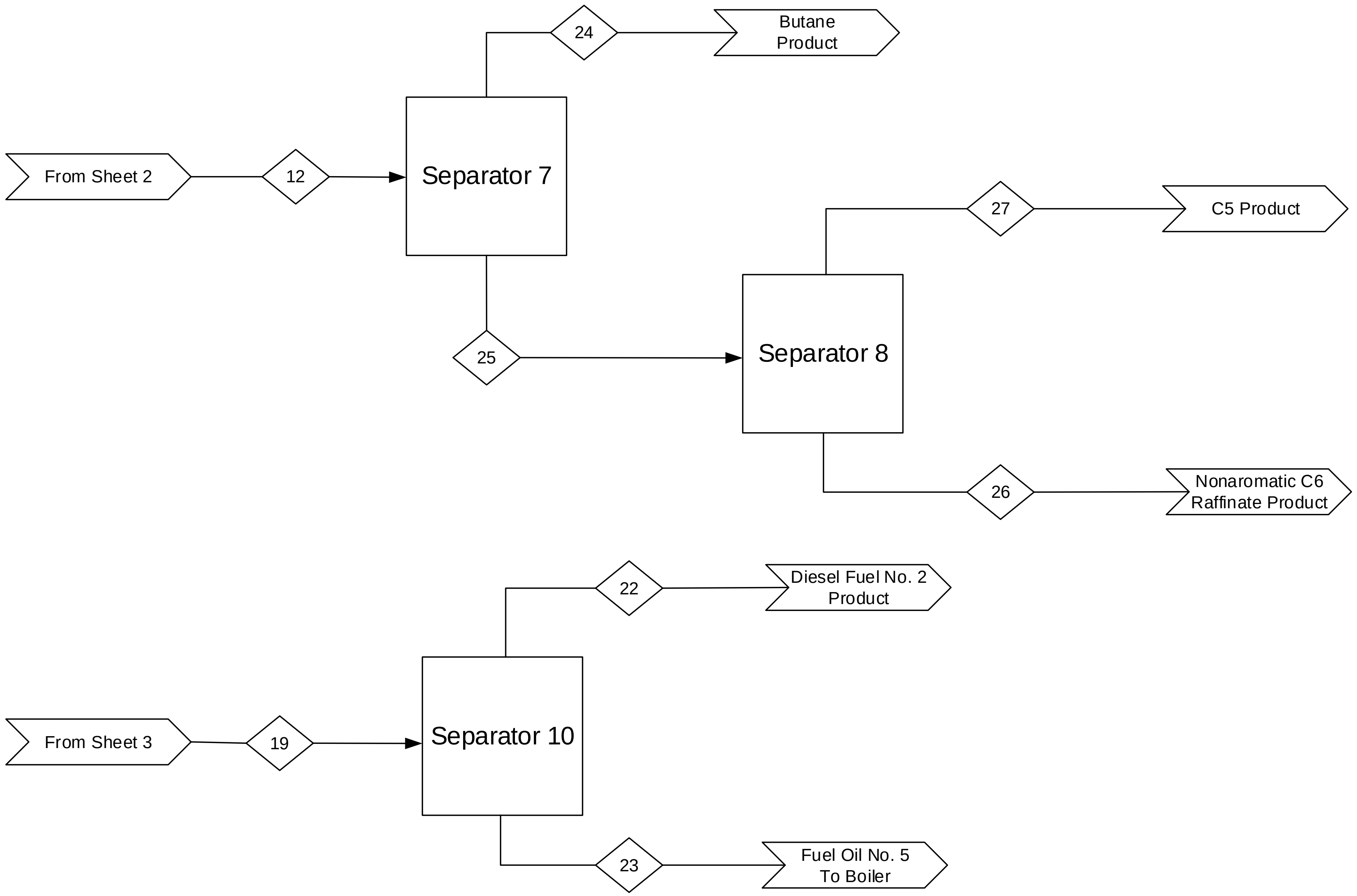
Drawing Type

Block Flow Diagram

Title

Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Alternative Base Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-21-16	00-A-002/3	0



Component/Stream (lb/min)	12	19	22	23	24	25	26	27
C4-C6	190	0	0	0	0	0	0	0
C4	0	0	0	0	50	0	0	0
C5-C6	0	0	0	0	0	140	0	0
C5	0	0	0	0	0	0	0	50
C6	0	0	0	0	0	0	90	0
C15-C22	0	0	470	0	0	0	0	0
C23-C30	0	0	0	10	0	0	0	0
C15-C30	0	480	0	0	0	0	0	0
Total	190	480	470	10	50	140	90	50

Notes

1. Drawing not to scale.

2. Mass balance may be off due to rounding.

3. Stream numbers do not correspond with PFD stream numbers.

4. Mass balances shown in lb/min.

5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

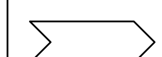
6. Assume 100% separation in separators.

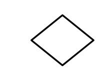
7. Separator 7: Separates butane byproduct from C5 and C6 byproducts.

Separator 8: Separates C5 byproduct from the C6 byproduct.

Separator 10: Separates the diesel fuel no. 2 product from the fuel oi no 5. product.

Special Symbols / Nomenclature


Input/Output


Stream Indicator

Reference Drawings:

Input/Output Diagram
00-A-001

Process Flow Diagram
00-A-003

Drawing Type

Block Flow Diagram

Title

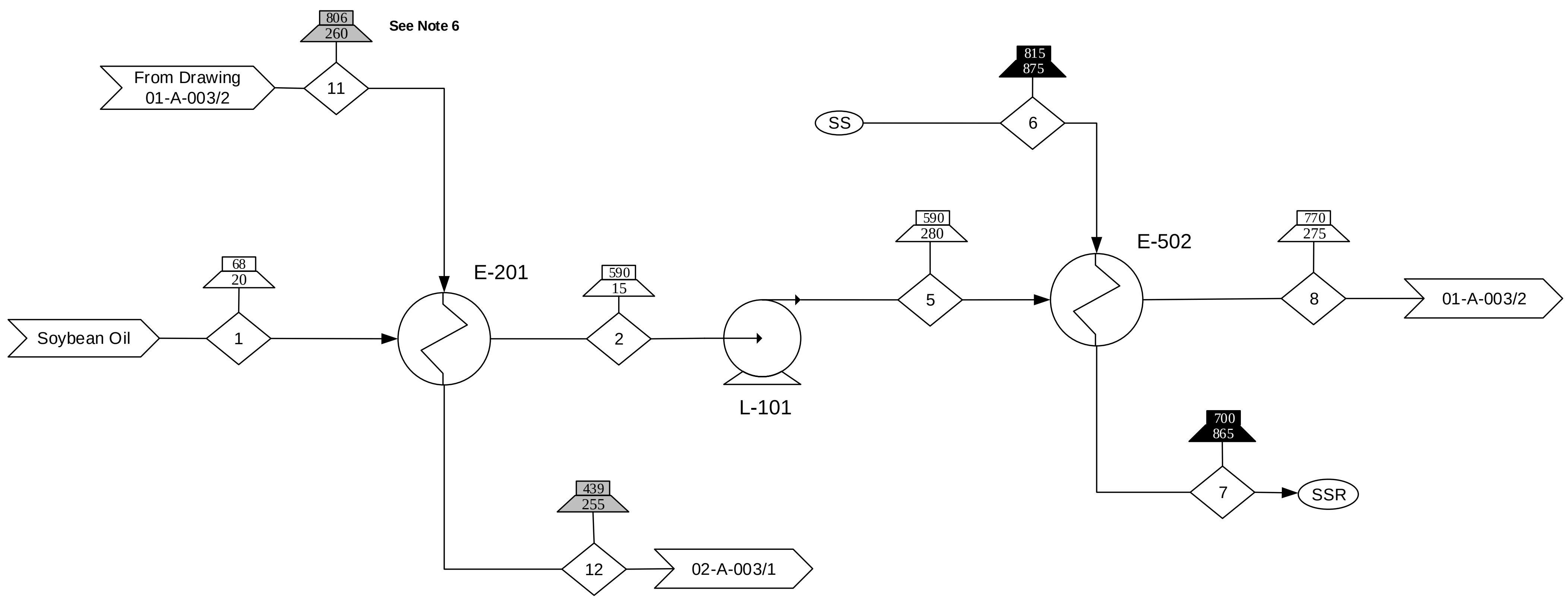
Biorefinery Based on Noncatalytic Cracking of Triglyceride Oils Alternative Base Design

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-21-16	00-A-002/4	0

E-201 A/B
Post Cracking Cooler
Area = 3400 ft^2
Duty = 4.9 x 10^7 Btu/hr

E-502 A/B
TTCR Preheat
Area = 3100 ft^2
Duty = 2.1 x 10^7 Btu/hr

L-101 A/B
PreCracking Pump
Power = 72 hp



Component/Stream (lb/min)	1	2	5	6	7	8	11	12
Soybean Oil	2200	2200	2200	0	0	2200	0	0
C1-C50	0	0	0	0	0	0	2200	2200
Water	0	0	0	5300	5300	0	0	0
Total	2200	2200	2200	5300	5300	2200	2200	2200

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 11 and 12 is an organic, aqueous, gaseous three phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
SS Superheated Steam
SSR Superheated Steam Recycle

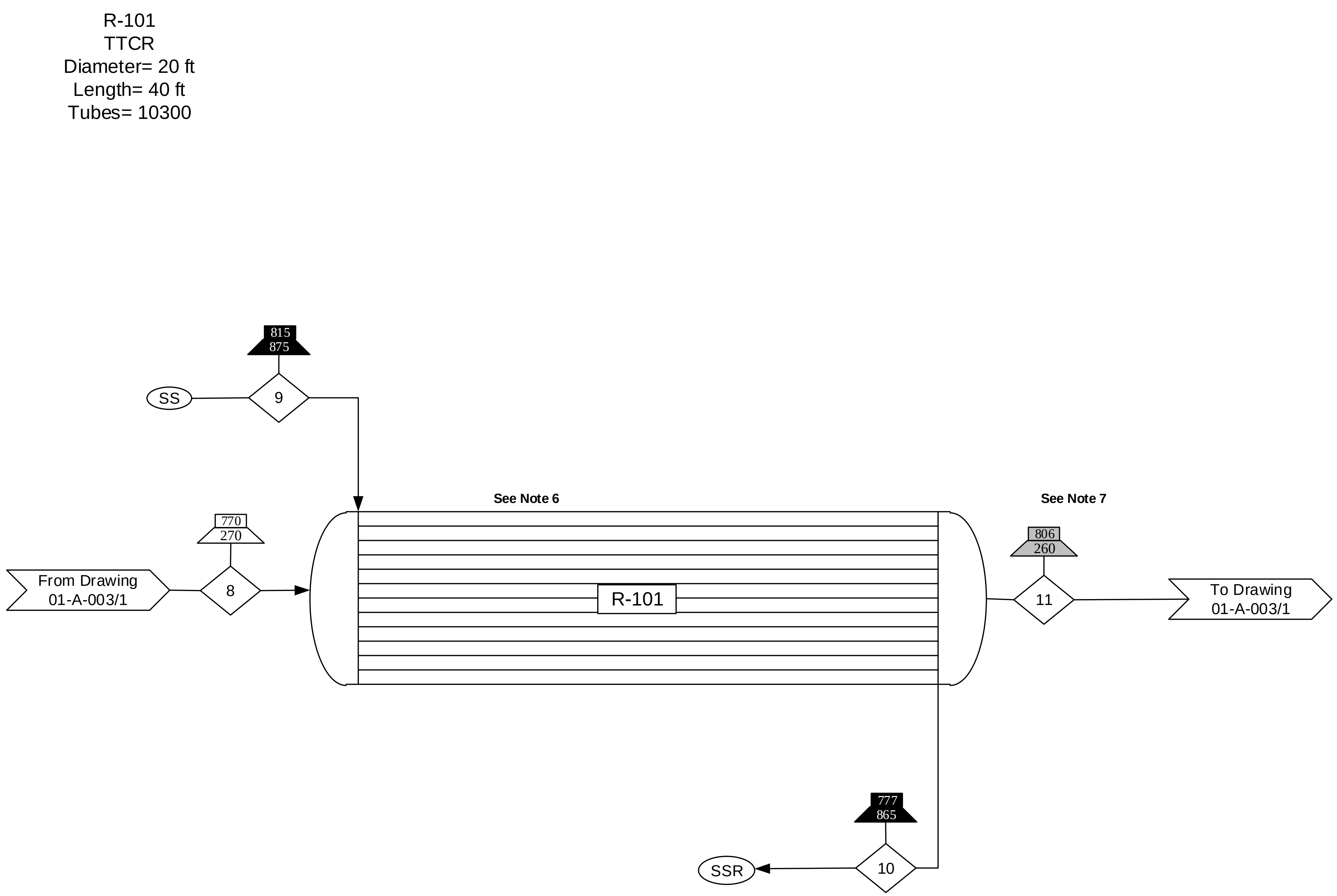
Reference Drawings:

Input/Output Diagram
00-A-001
Block Flow Diagrams
00-A-002
Process Flow Diagrams
01-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design- Thermal Cracking Section

By/Date	DWG # / Sheet #	Rev
SAB/ 12-27-16	01-A-003/1	0

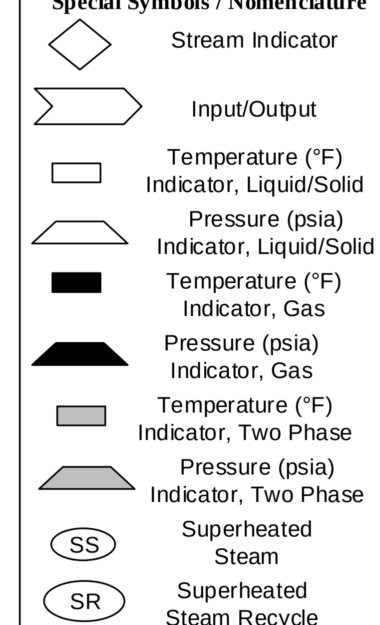


Component/Stream (lb/min)	8	9	10	11
Soybean Oil	2200	0	0	0
C1-C50	0	0	0	2200
Water	0	18000	18000	0
Total	2200	18000	18000	2200

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. R-101 has a residence time of 1.17 hr.
7. Stream 11 is composed of a gas phase stream with entrained liquid tars.

Special Symbols / Nomenclature



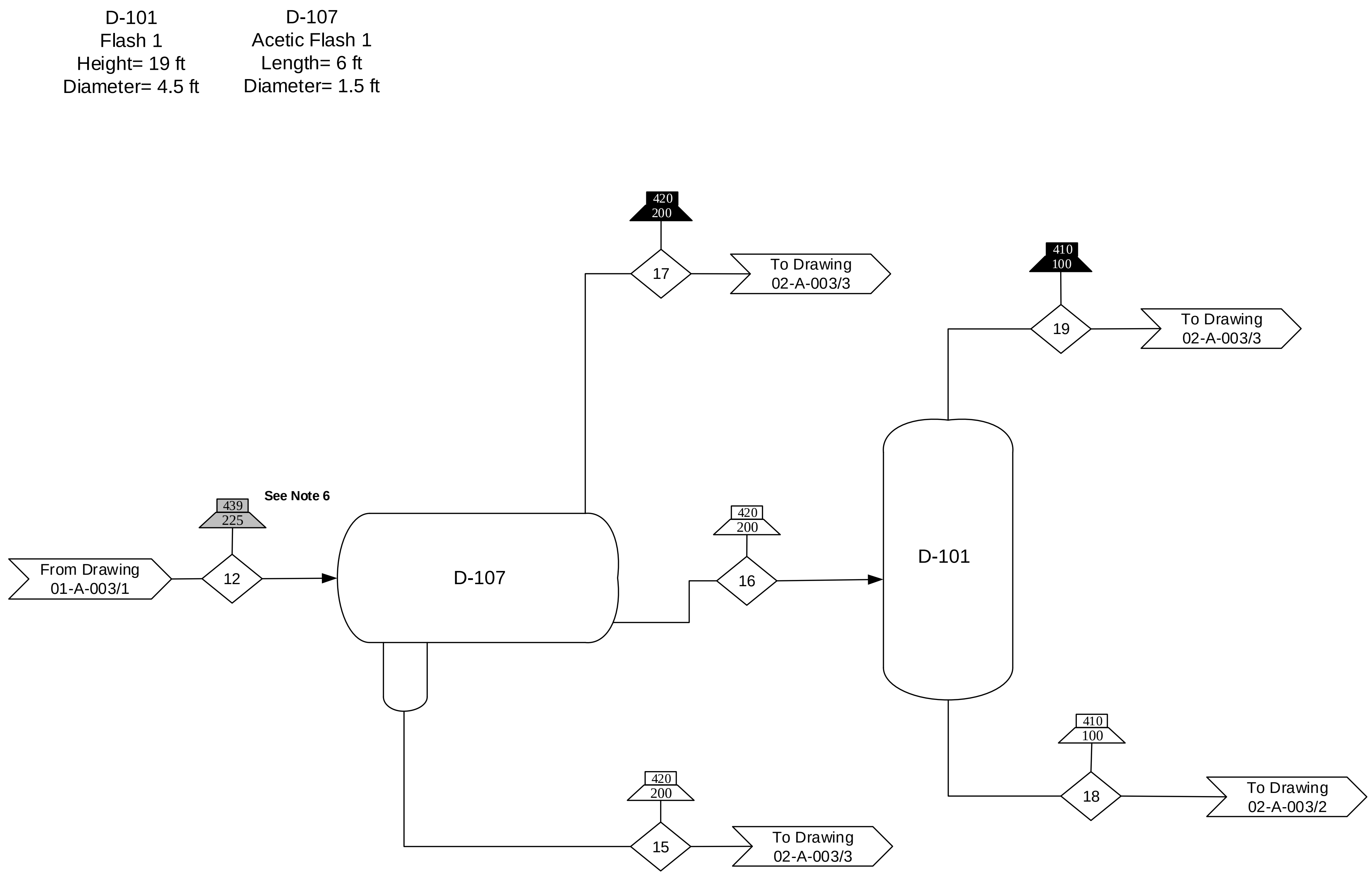
Reference Drawings:

Input/Output Diagrams
00-A-001
Block Flow Diagrams
00-A-002
Process Flow Diagrams
01-A-003
02-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design- Thermal Cracking Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-27-16	01-A-003/2	0

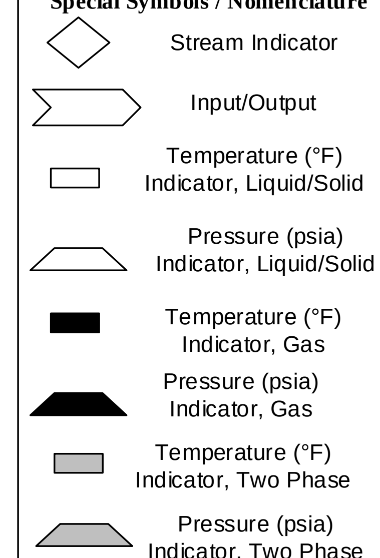


Component/Stream (lb/min)	12	15	16	17	18	19
C1-C50	2200	0	0	0	0	0
C1-C8	0	0	0	460	0	20
C7-C50	0	0	1700	0	1700	0
Acetic Acid	0	6	0	0	0	0
Propionic Acid	0	1	0	0	0	0
Total	2200	7	1700	460	1700	20

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 12 is composed of an aqueous and organic three phase stream.

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagram
00-A-007
Block Flow Diagram
00-A-008
Process Flow Diagrams
01-A-003
02-A-003

Drawing Type
Process Flow Diagram

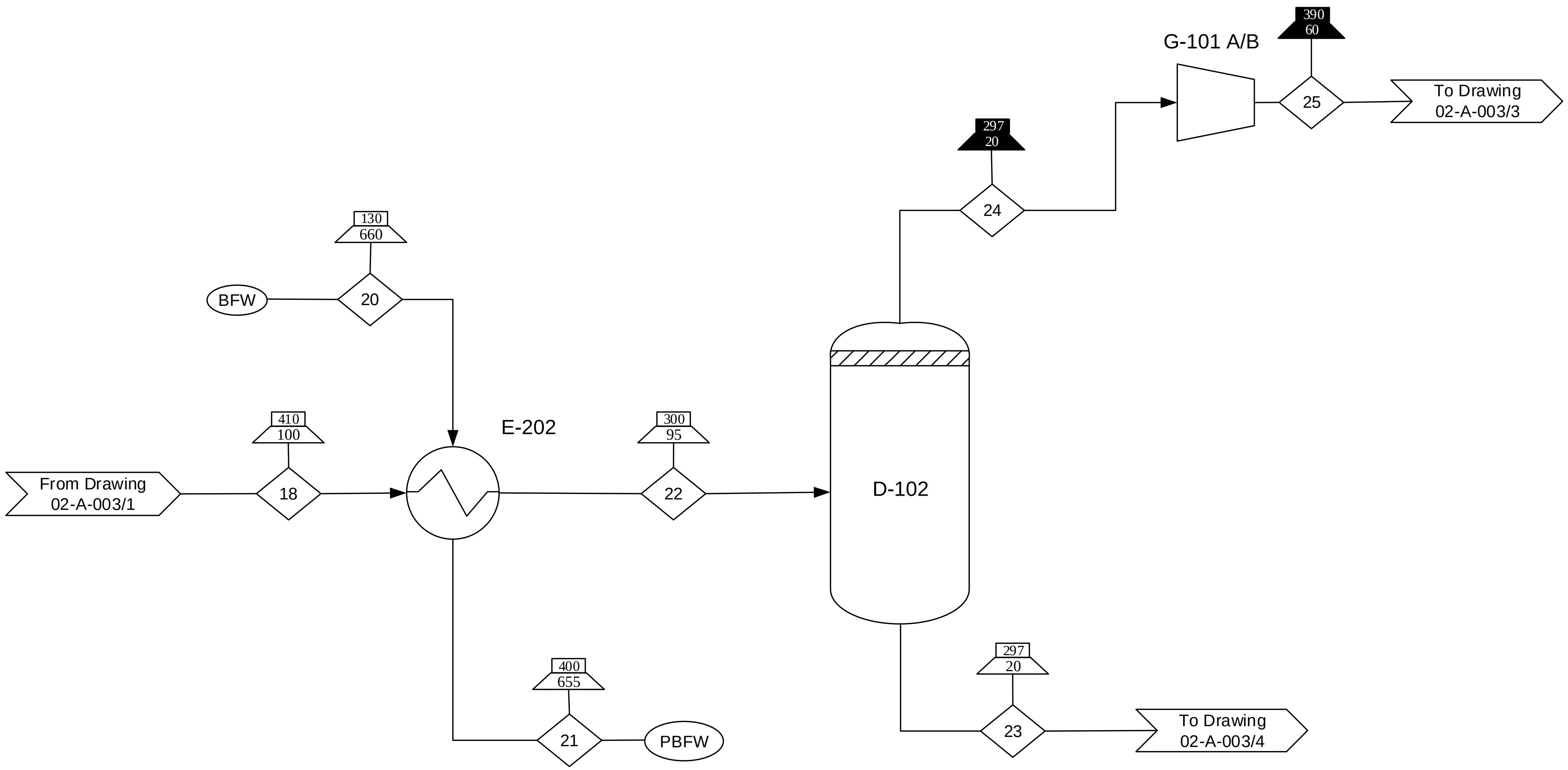
Title
Biorefinery Alternative Base Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-28-16	02-A-003/1	0

D-102
Flash 2
Height= 17.5 ft
Diameter= 4.5 ft

E-202 A/B
Flash 2 Cooler
Area= 1800 ft^2
Duty= 9.3×10^6 Btu/hr

G-101 A/B
Flash 2 Compressor
Power= 22 hp



Component/Stream (lb/min)	18	20	21	22	23	24	25
C1-C8	0	0	0	0	0	20	20
C7-C50	1700	0	0	1700	1700	0	0
Water	0	560	560	0	0	0	0
Total	1700	560	560	1700	1700	20	20

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

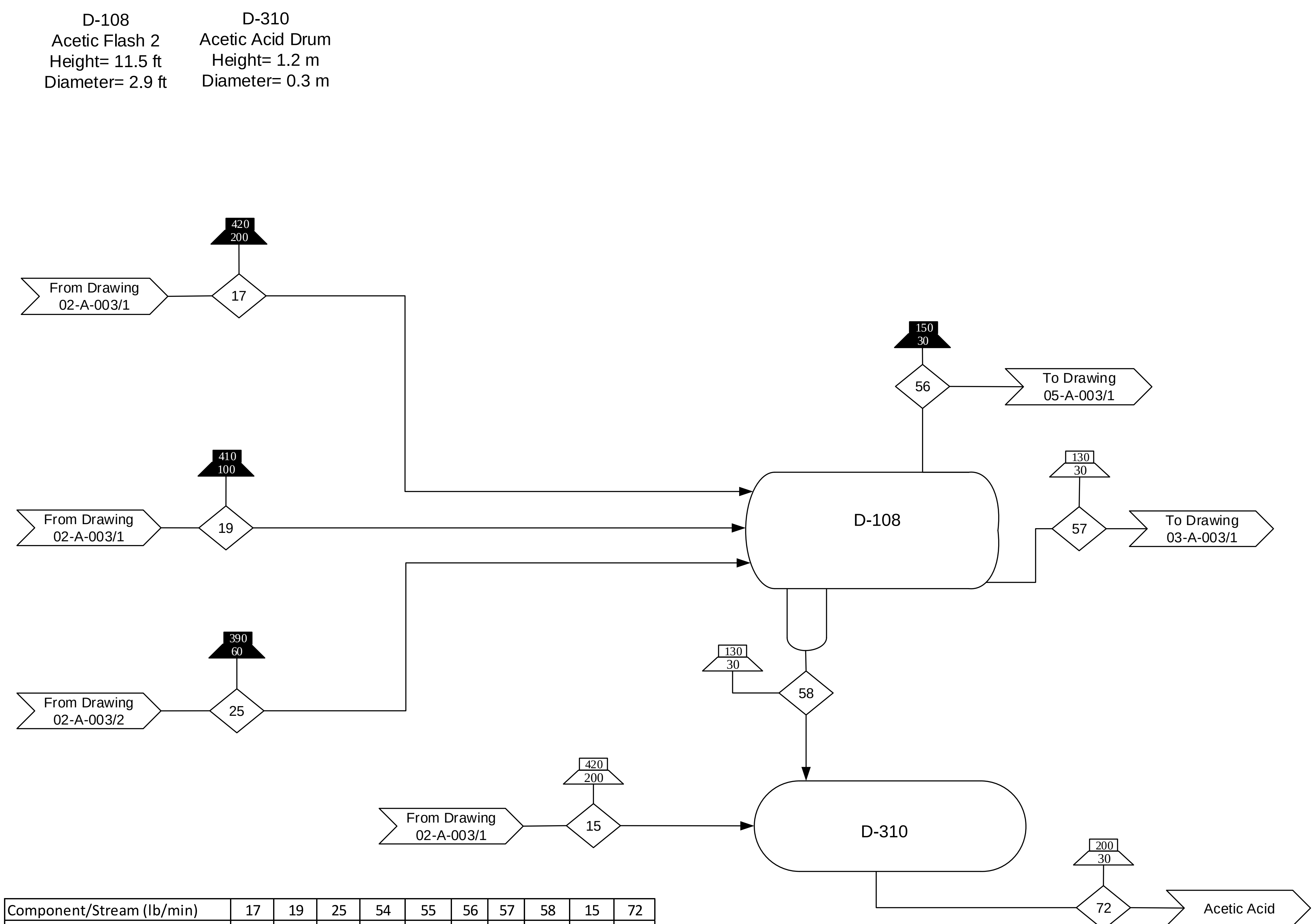
Reference Drawings:

Input/Output Diagrams
00-A-001
Block Flow Diagrams
00-A-002
Process Flow Diagrams
02-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-28-16	02-A-003/2	0



Component/Stream (lb/min)	17	19	25	54	55	56	57	58	15	72
C1-C8	460	20	20	0	0	0	0	0	0	0
C1-C6	0	0	0	0	0	380	0	0	0	0
C6-C8	0	0	0	0	0	0	120	0	0	0
Water	0	0	0	4100	4100	0	0	0	0	0
Acetic Acid	0	Trace	Trace	0	0	Trace	0	3	6	9
Propionic Acid	0	Trace	Trace	0	0	0	0	Trace	1	1
Total	460	20	20	4100	4100	380	120	3	7	10

Notes

1. Drawing is not to scale.

2. Mass balances may be off due to rounding.

3. Mass balances are shown in lb/min.

4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator

Input/Output

Temperature (°F) Indicator, Liquid/Solid

Pressure (psia) Indicator, Liquid/Solid

Temperature (°F) Indicator, Gas

Pressure (psia) Indicator, Gas

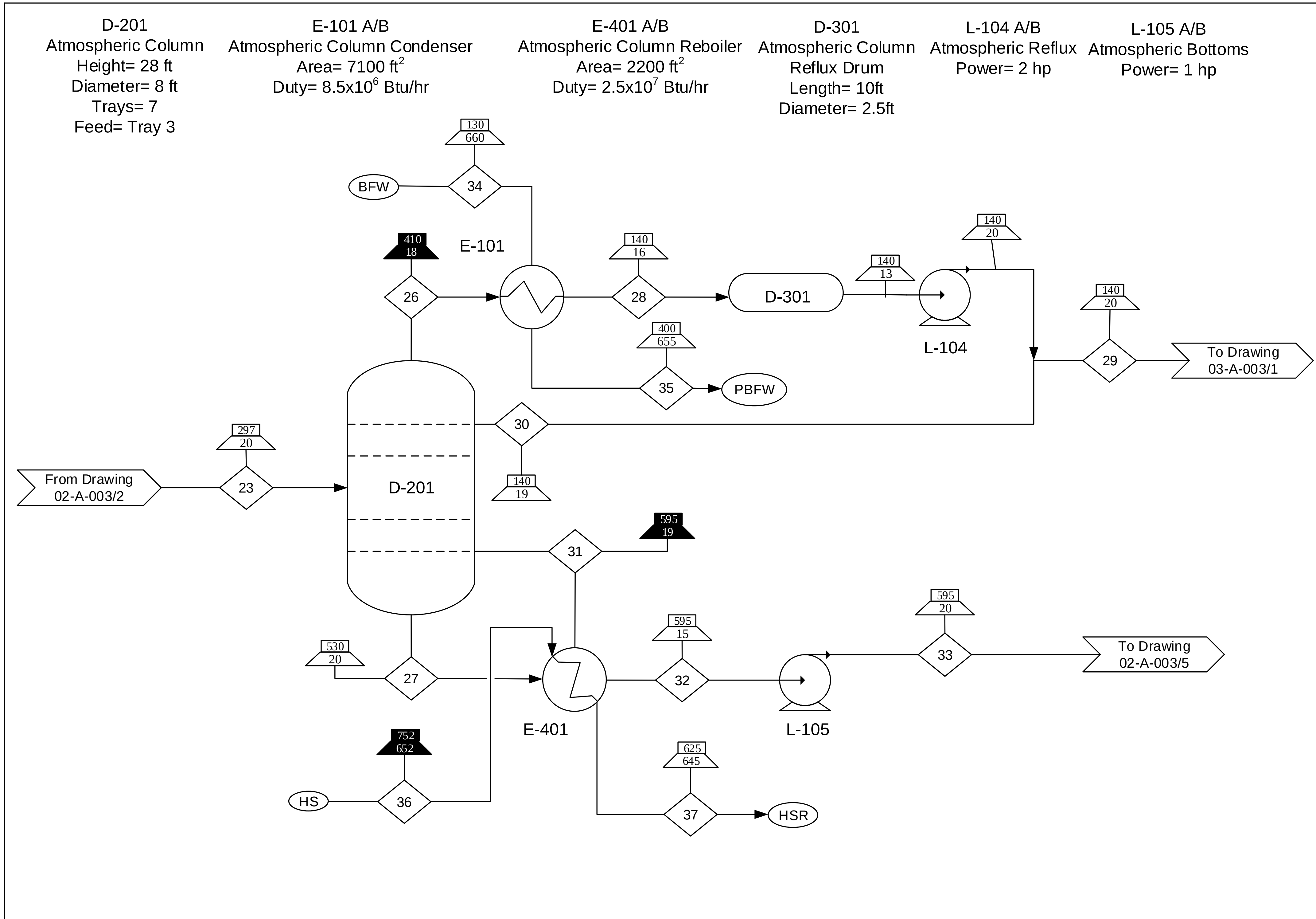
Reference Drawings:

Input/Output Diagram
00-A-001
Block Flow Diagram
00-A-002
Process Flow Diagrams
02-A-003
03-A-003
05-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-29-16	02-A-003/3	0



Component/Stream (lb/min)	23	26	27	28	29	30	31	32	33	34	35	36	37
C7-C12	0	400	0	400	370	30	0	0	0	0	0	0	0
C7-C50	1700	0	3200	0	0	0	1900	0	0	0	0	0	0
C13-C50	0	0	0	0	0	0	0	1300	1300	0	0	0	0
Water	0	0	0	0	0	0	0	0	0	510	510	5600	5600
Total	1700	400	3200	400	370	30	1900	1300	1300	510	510	5600	5600

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
HS High Pressure Steam
HSR High Pressure Steam Recycle
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagram
00-A-001
Block Flow Diagram
00-A-002
Process Flow Diagrams
02-A-003
03-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-28-16	02-A-003/4	0

D-202
Vacuum Column
Height= 67 ft
Diameter= 9.5 ft
Trays= 20
Feed= Tray 5

E-102 A/B
Vacuum Column Condenser
Area= 1300 ft^2
Duty= 1.9×10^7 Btu/hr

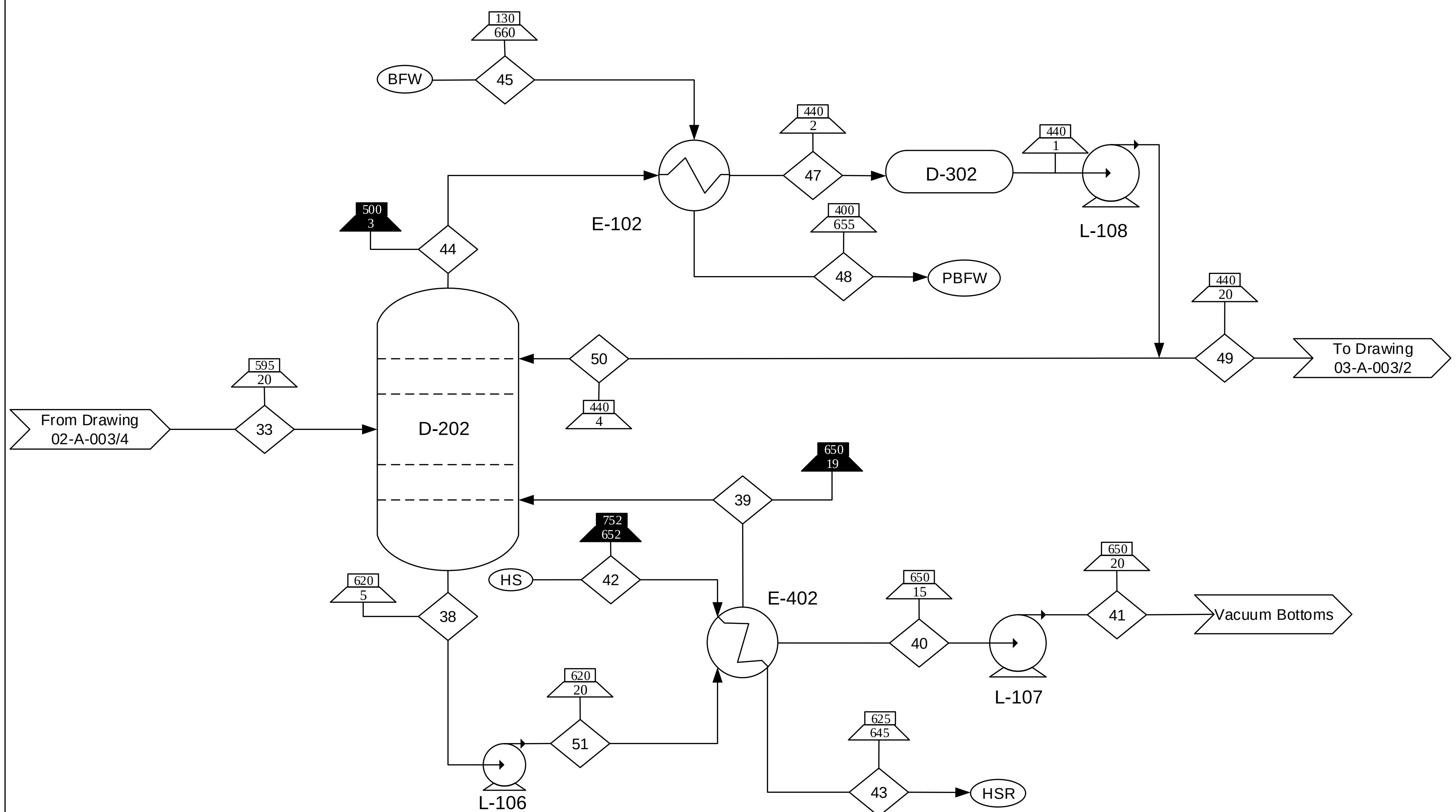
E-402 A/B
Vacuum Column Reboiler
Area= 9030 ft^2
Duty= 1.5×10^7 Btu/hr

D-302
Vacuum Column Reflux Drum
Length= 16 ft
Diameter= 4 ft

L-106 A/B
Vacuum Column Bottoms
Power= 6 hp

L-107 A/B
Vacuum Bottoms
Power= 1 hp

L-108 A/B
Vacuum Reflux
Power= 6 hp



Component/Stream (lb/min)	33	38	39	40	41	42	43	44	45	46	47	48	49	50	51
C12-C50	1300	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C12-C30	0	0	0	0	0	0	0	1700	0	1700	1700	0	700	950	0
C30-C50	0	2200	1600	2200	620	0	0	0	0	0	0	0	0	0	2200
Water	0	0	0	0	0	3300	3300	0	1100	0	0	1100	0	0	0
Total	1300	2200	1600	2200	620	3300	3300	1700	1100	1700	1700	1100	700	950	2200

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
HS — High Pressure Steam
HSR — High Pressure Steam Recycle
BFW — Boiler Feed Water
PBFW — Preheated Boiler Feed Water

Reference Drawings:

Input/Output Diagrams
00-A-001
Block Flow Diagrams
00-A-002
Process Flow Diagrams
02-A-003
03-A-003

Drawing Type
Process Flow Diagram

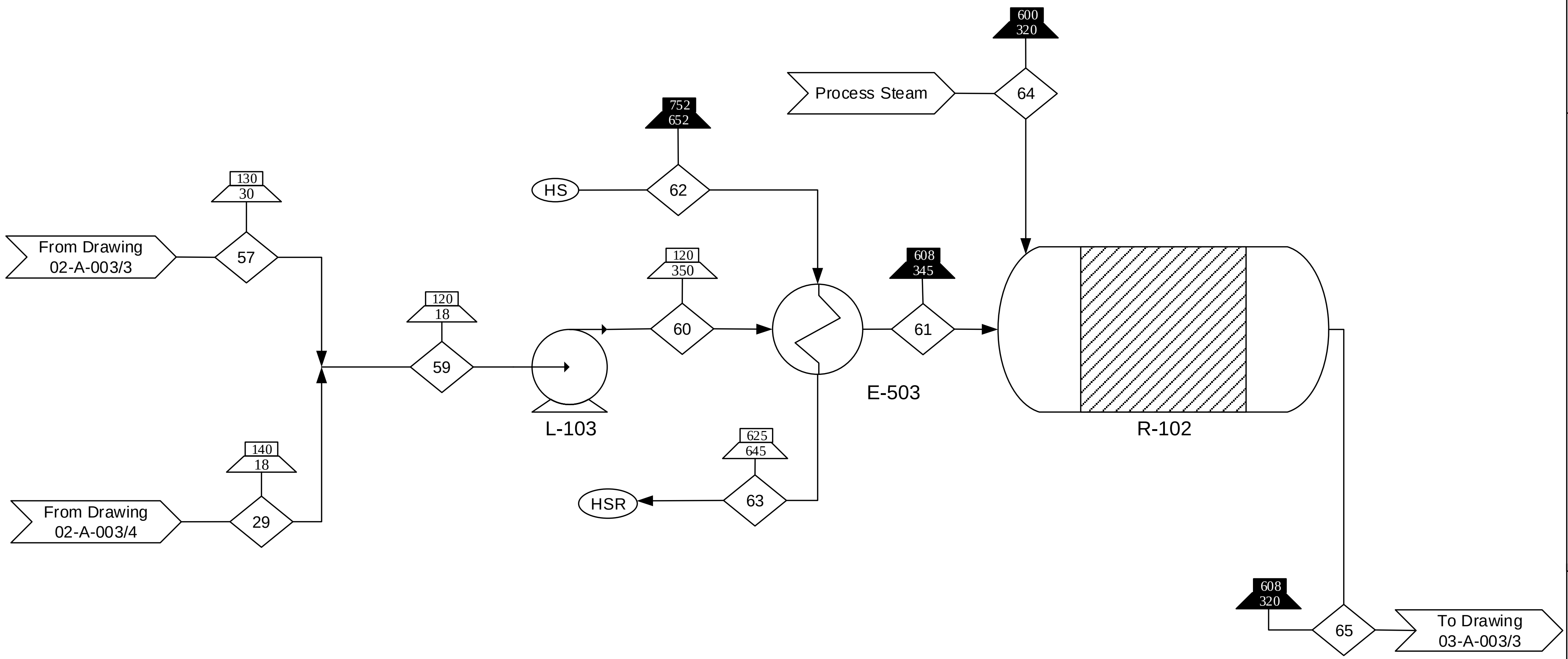
Title
Biorefinery Alternative Base Design- Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-28-16	02-A-003/5	0

R-102 A/B
Naphtha Decarboxylation Reactor
Diameter= 9 ft
Length= 56 ft
Catalyst= 7700 ft^3

E-503 A/B
Naphtha Decarbox Heater
Area= 460 ft^2
Duty= 1.3×10^7 Btu/hr

L-103 A/B
PreNaphtha Decarbox Pump
Power= 23 hp



Component/Stream (lb/min)	29	57	59	60	61	62	63	64	65
C6-C8	0	120	0	0	0	0	0	0	0
C7-C12	370	0	0	0	0	0	0	0	0
C6-C12	0	0	490	490	490	0	0	0	0
C1-C12	0	0	0	0	0	0	0	0	510
Water	0	0	0	0	0	2800	2800	15	0
Total	370	120	490	490	490	2800	2800	15	510

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
HS High Pressure Steam
HSR High Pressure Steam Recycle

Reference Drawings:

Input/Output Diagram
00-A-001
Block Flow Diagram
00-A-002
Process Flow Diagrams
02-A-003
03-A-003

Drawing Type
Process Flow Diagram

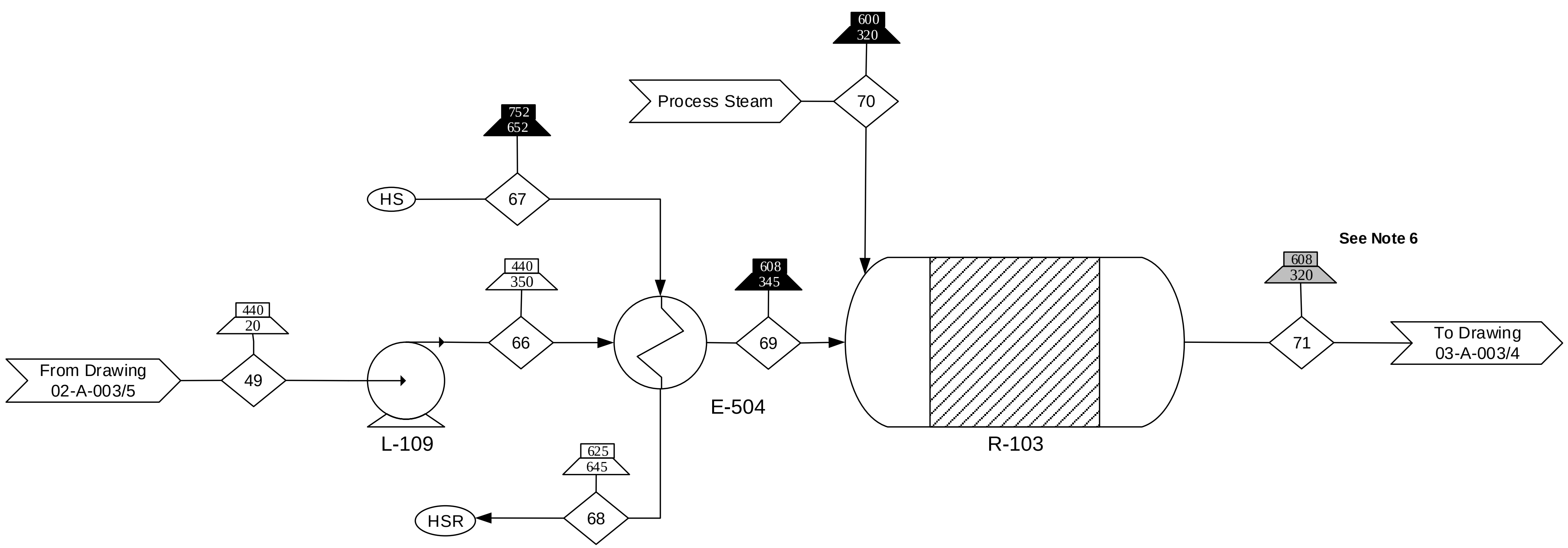
Title
Biorefinery Alternative Base Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-29-16	03-A-003/1	0

R-103 A/B
Diesel Decarboxylation Reactor
Diameter= 11 ft
Length= 63 ft
Catalyst= 11000 ft^3

E-504 A/B
Diesel Decarbox Heater
Area= 440 ft^2
Duty= $6.1x10^6$ Btu/hr

L-109 A/B
Pre Diesel Decarbox Pump
Power= 39 hp



Component/Stream (lb/min)	49	66	67	68	69	70	71
C12-C30	700	700	0	0	700	0	0
C1-C30	0	0	0	0	0	0	720
Water	0	0	1400	1400	0	21	0
Total	700	700	1400	1400	700	21	720

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 71 is composed of a liquid gas two phase stream.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
HS High Pressure Steam
HSR High Pressure Steam Recycle

Reference Drawings:

Input/Output Diagram
00-A-001
Block Flow Diagram
00-A-002
Process Flow Diagrams
02-A-003
03-A-003

Drawing Type
Process Flow Diagram

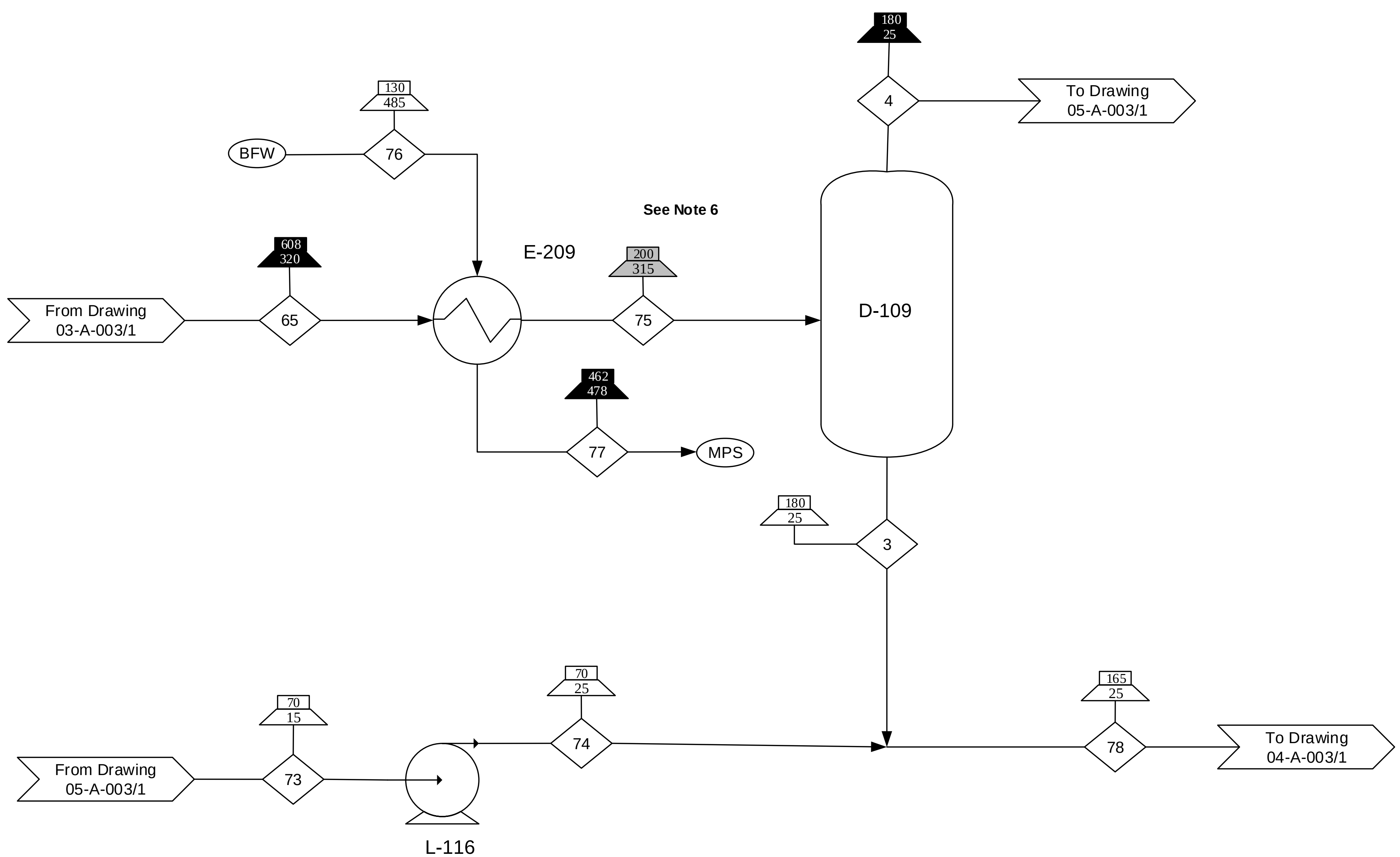
Title
Biorefinery Alternative Base Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-29-16	03-A-003/2	0

D-109
Flash 7
Height= 9 ft
Diameter= 2.5 ft

E-209 A/B
Post Naphtha Decarbox Cooler
Area = 800 ft^2
Duty = 1.2 x 10^7 Btu/hr

L-116 A/B
Flash 5 Pump
Power = 1 hp

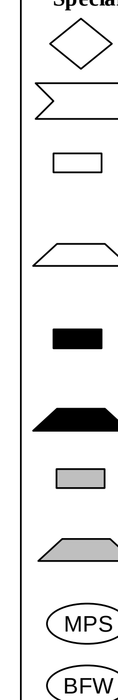


Component/Stream (lb/min)	65	73	74	75	76	77	3	4	78
C1-C12	510	0	0	510	0	0	0	0	460
C6-C9	0	50	50	0	0	0	0	0	0
C1-C4	0	0	0	0	0	0	0	100	0
C4-C12	0	0	0	0	0	0	410	0	0
Water	0	0	0	0	200	200	0	0	0
Total	510	50	50	510	200	200	410	100	460

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
6. Stream 75 is composed of a liquid and gas two phase stream.

Special Symbols / Nomenclature



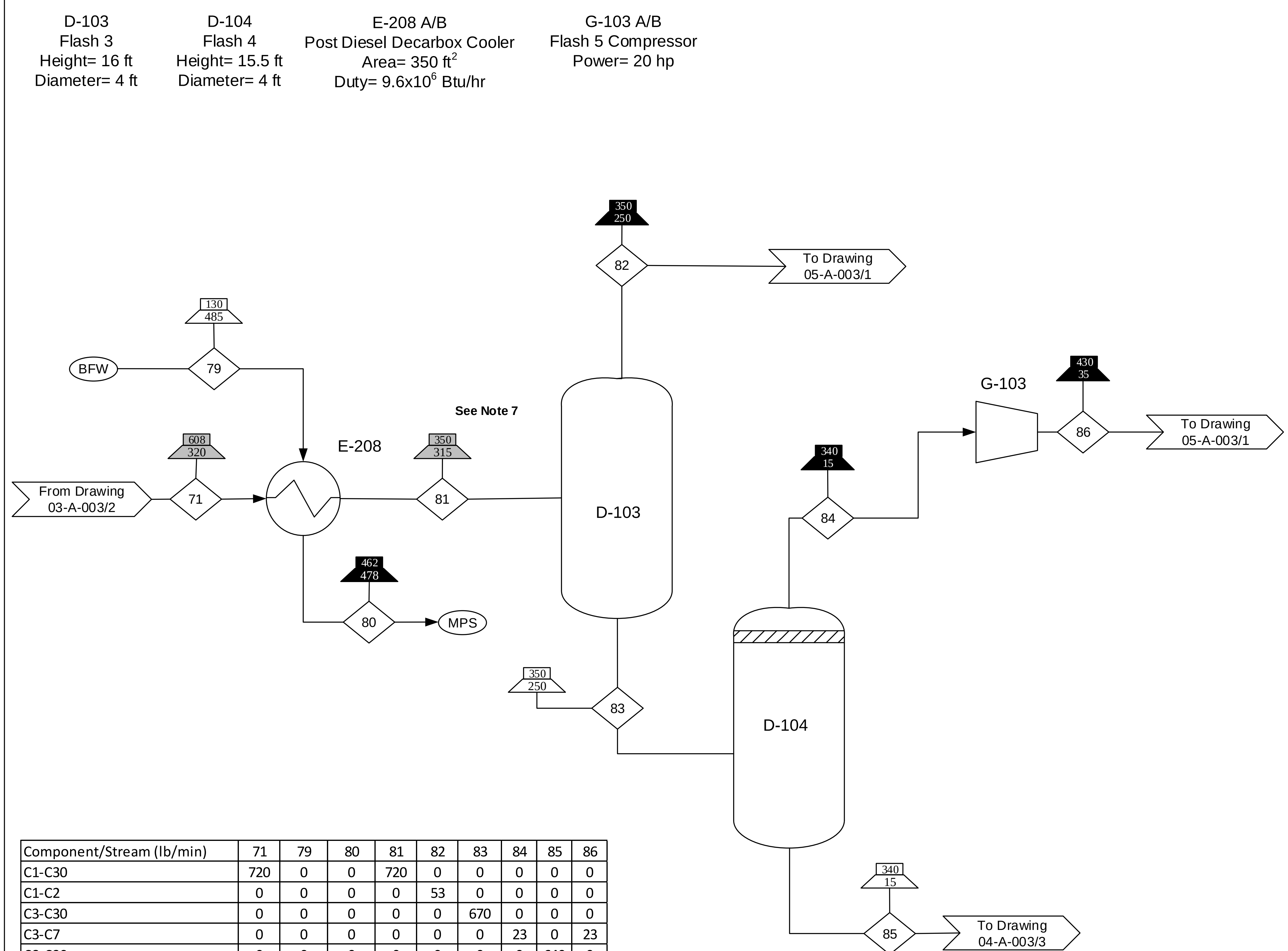
Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
Medium Pressure Steam
Boiler Feed Water

Reference Drawings:
Input/Output Diagram
00-A-001
Block Flow Diagram
00-A-002
Process Flow Diagrams
03-A-003
04-A-03
05-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-29-16	03-A-003/3	0



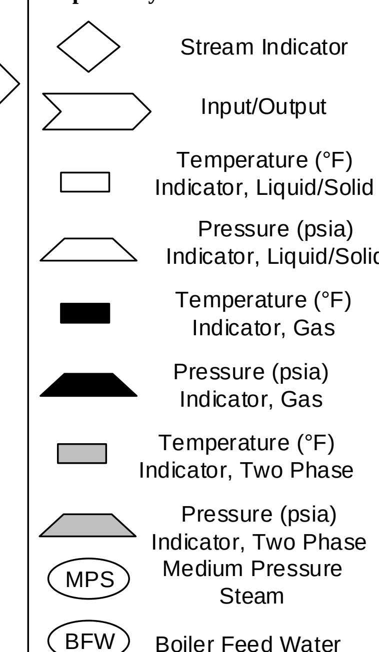
Component/Stream (lb/min)	71	79	80	81	82	83	84	85	86
C1-C30	720	0	0	720	0	0	0	0	0
C1-C2	0	0	0	0	53	0	0	0	0
C3-C30	0	0	0	0	0	670	0	0	0
C3-C7	0	0	0	0	0	0	23	0	23
C8-C30	0	0	0	0	0	0	0	640	0
Water	0	150	150	0	0	0	0	0	0
Total	720	150	150	720	53	670	23	640	23

300

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
6. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
7. Streams 71 and 81 are composed of a liquid and gas two phase stream.

Special Symbols / Nomenclature



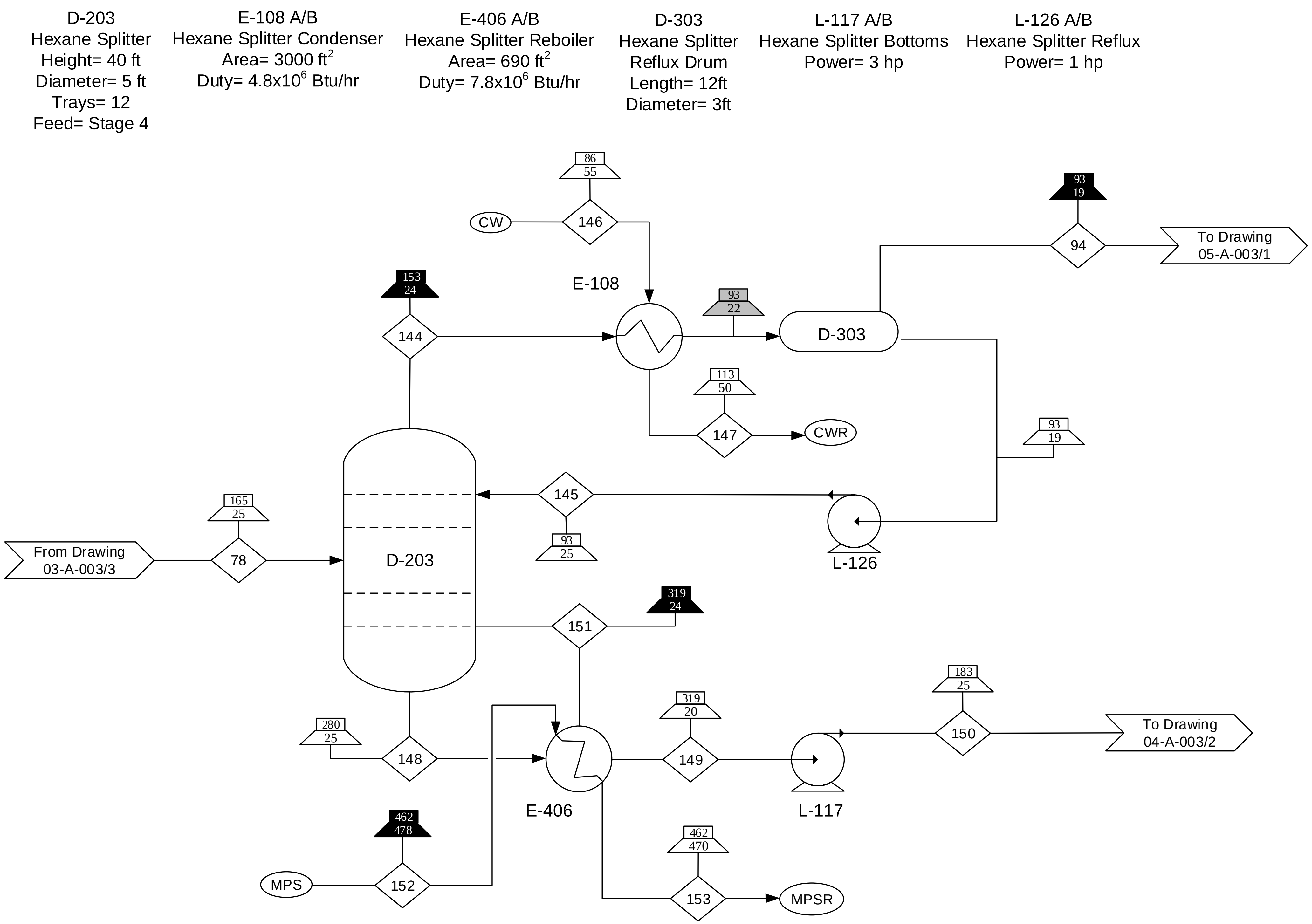
Reference Drawings:

Process Flow Diagrams
03-A-003
04-A-003
05-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Decarboxylation Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-29-16	03-A-003/4	0



Component/Stream (lb/min)	78	94	144	145	146	147	148	149	150	151	152	153
C1-C12	460	0	0	0	0	0	0	0	0	0	0	0
C1-C6	0	30	380	250	0	0	0	0	0	0	0	0
C7-C12	0	0	0	0	0	0	1100	420	420	680	0	0
Water	0	0	0	0	3000	3000	0	0	0	0	170	170
Total	460	30	380	250	3000	3000	1100	420	420	680	170	170

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
MPS Medium Pressure Steam
MPSR Medium Pressure Steam Recycle
CW Cooling Water
CWR Cooling Water Recycle

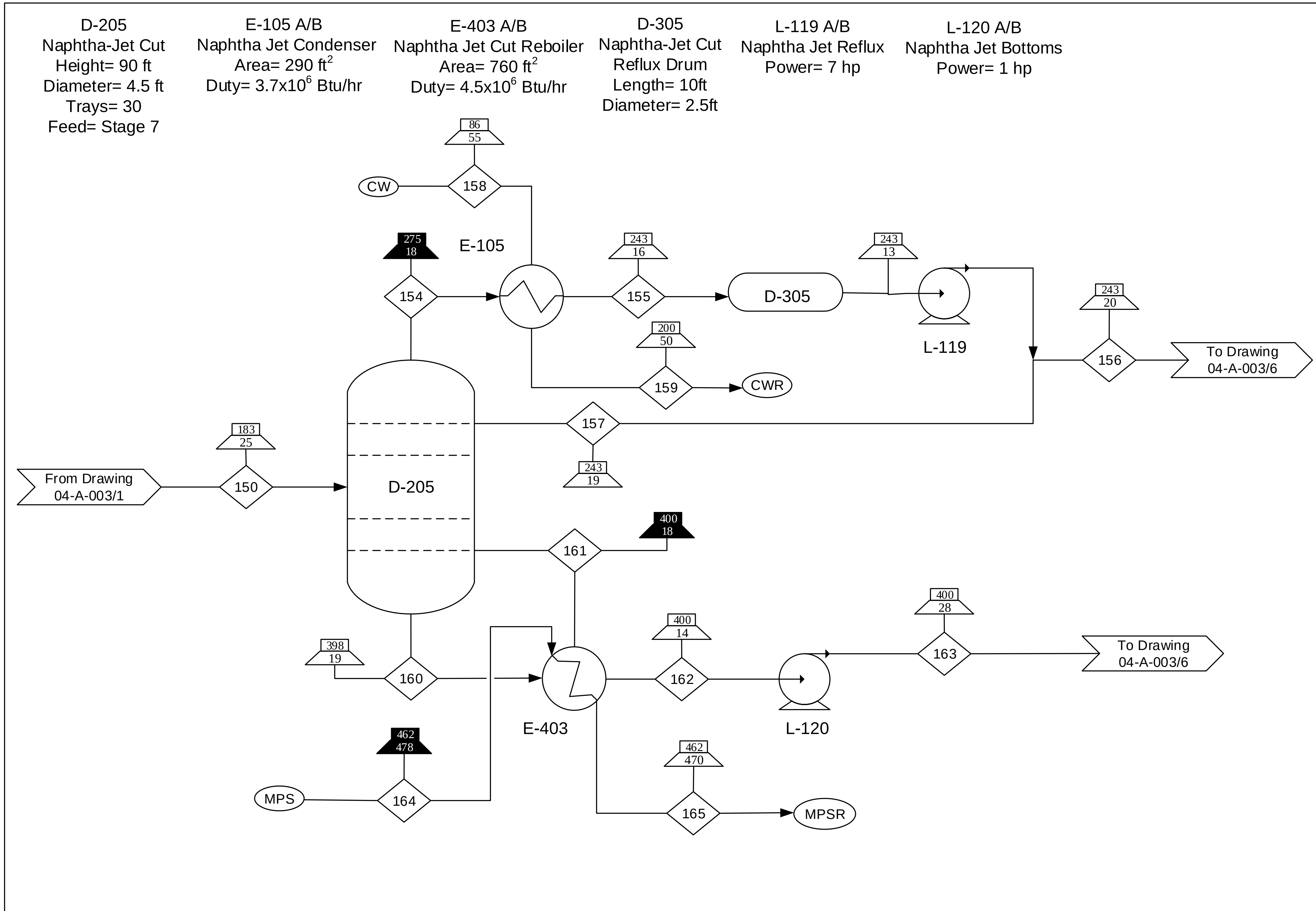
Reference Drawings:

Input/Output Diagram
00-A-001
Block Flow Diagram
00-A-002
Process Flow Diagrams
03-A-003
04-A-003
05-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-3-17	04-A-003/1	0

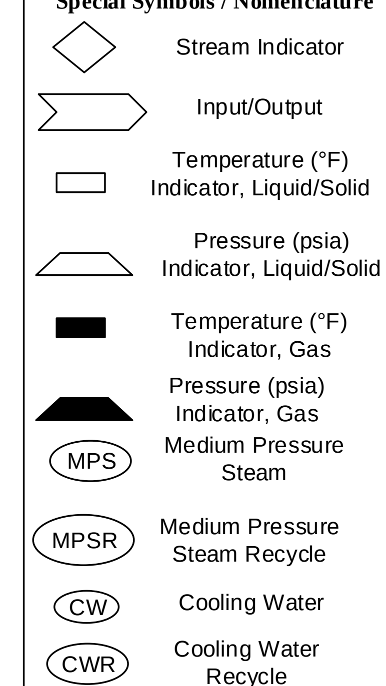


Component/Stream (lb/min)	150	154	155	156	157	158	159	160	161	162	163	164	165
C7-C12	420	0	0	0	0	0	0	0	0	0	0	0	0
C7-C9	0	330	150	150	180	0	0	0	0	0	0	0	0
C9-C12	0	0	0	0	0	0	0	720	450	270	270	0	0
Water	0	0	0	0	0	2300	2300	0	0	0	0	100	100
Total	420	330	150	150	180	2300	2300	720	450	270	270	100	100

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagram
00-A-001
Block Flow Diagram
00-A-002
Process Flow Diagrams
04-A-003

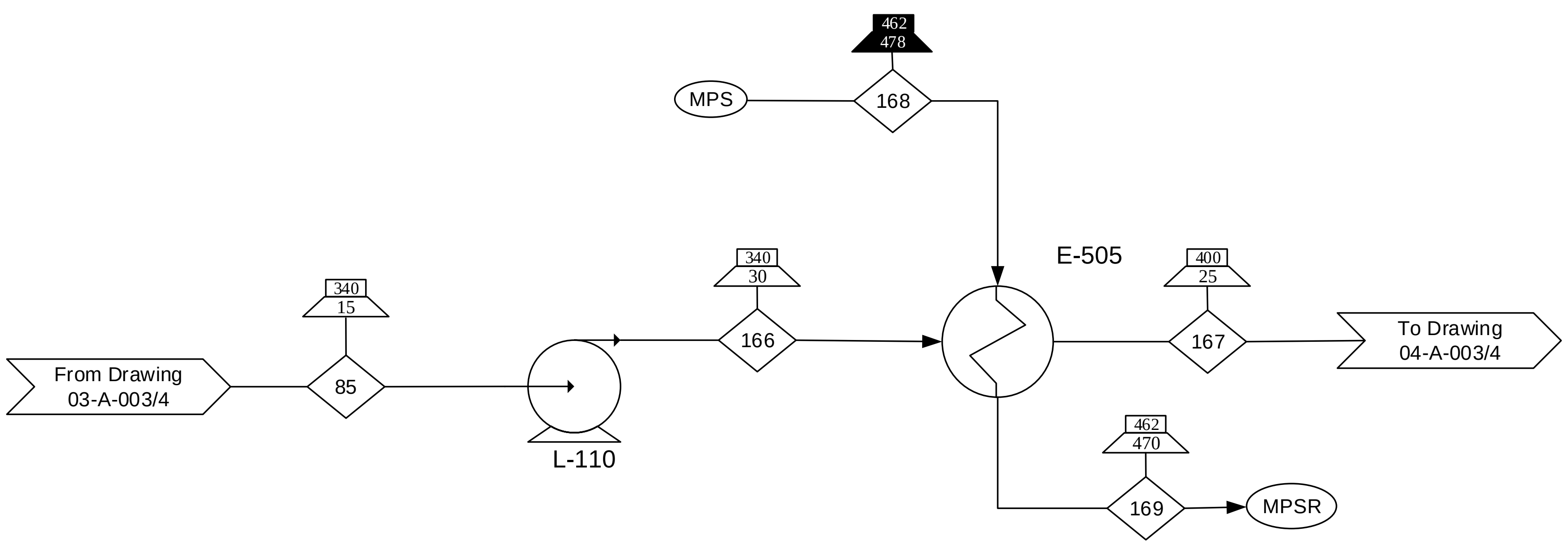
Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-3-17	04-A-003/2	0

E-505 A/B
Pre Jet Diesel Cut Heat
Area = 240 ft^2
Duty = 1.8 x 10^6 Btu/hr

L-110 A/B
Pre Jet Diesel Cut Heat Pump
Power = 2 hp



Component/Stream (lb/min)	85	166	167	168	169
C8-C30	640	640	640	0	0
Water	0	0	0	40	40
Total	640	640	640	40	40

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
MPS Medium Pressure Steam
MPSR Medium Pressure Steam Recycle

Reference Drawings:

Input/Output Diagram
00-A-001
Block Flow Diagram
00-A-002
Process Flow Diagrams
03-A-003
04-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-3-17	04-A-003/3	0

D-204
Jet Diesel Cut
Height= 80 ft
Diameter= 8.5 ft
Trays= 25
Feed= Stage 13

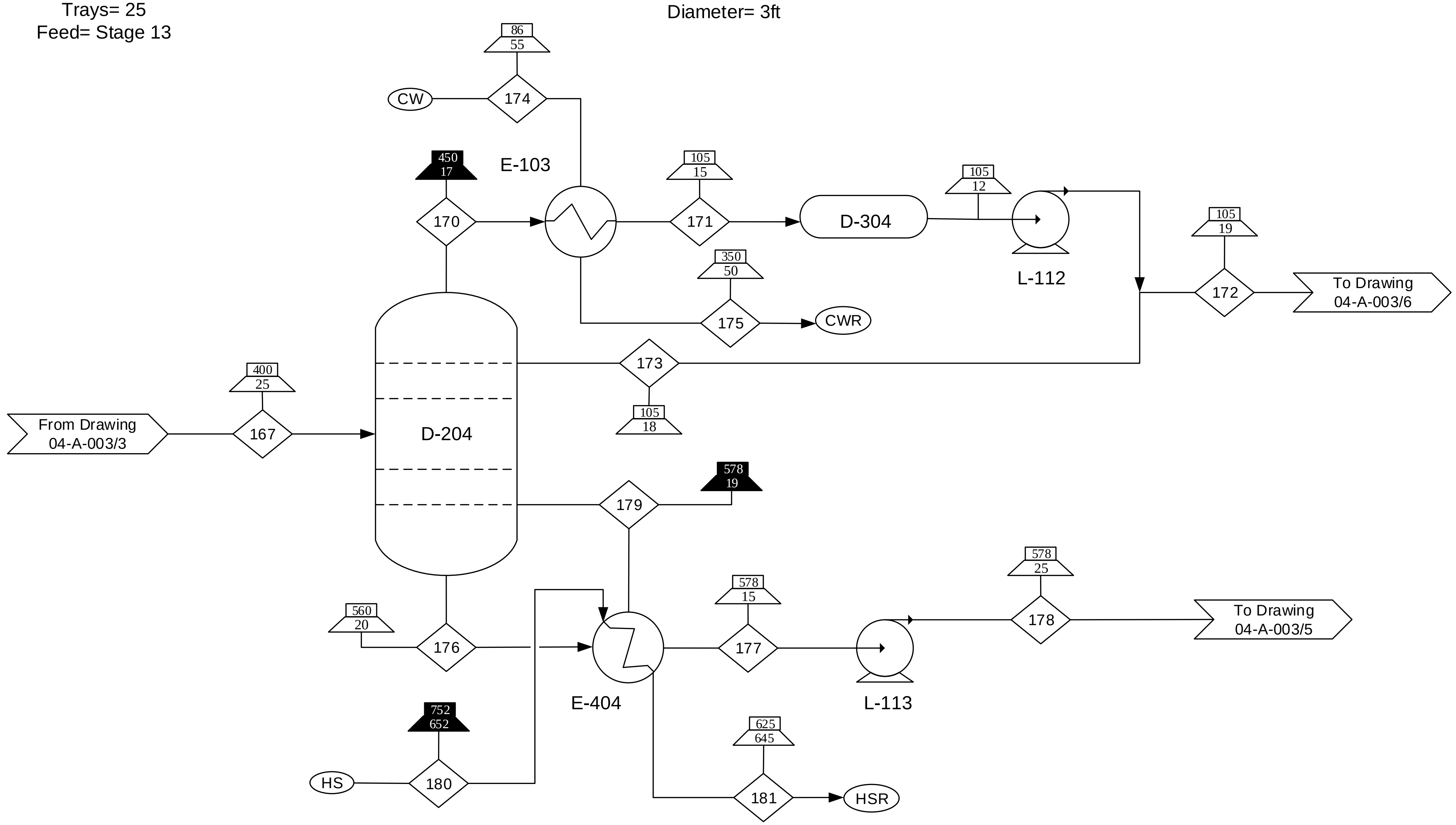
E-103 A/B
Jet Diesel Cut Condenser
Area= 1400 ft^2
Duty= $9.7x10^6$ Btu/hr

E-404 A/B
Jet Diesel Cut Reboiler
Area= 1800 ft^2
Duty= $1.2x10^7$ Btu/hr

D-304
Jet-Diesel Cut
Reflux Drum
Length= 12ft
Diameter= 3ft

L-112 A/B
Jet Diesel Cut Reflux
Power= 6 hp

L-113 A/B
Jet Diesel Cut Bottoms
Power= 1 hp



Component/Stream (lb/min)	167	170	171	172	173	174	175	176	177	178	179	180	181
C8-C30	640	0	0	0	0	0	0	0	0	0	0	0	0
C8-C15	0	410	410	160	250	0	0	0	0	0	0	0	0
C16-C30	0	0	0	0	0	0	0	1900	480	480	1400	0	0
Water	0	0	0	0	0	6000	6000	0	0	0	0	2700	2700
Total	640	410	410	160	250	6000	6000	1900	480	480	1400	2700	2700

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
HS High Pressure Steam
HSR High Pressure Steam Recycle
CW Cooling Water
CWR Cooling Water Recycle

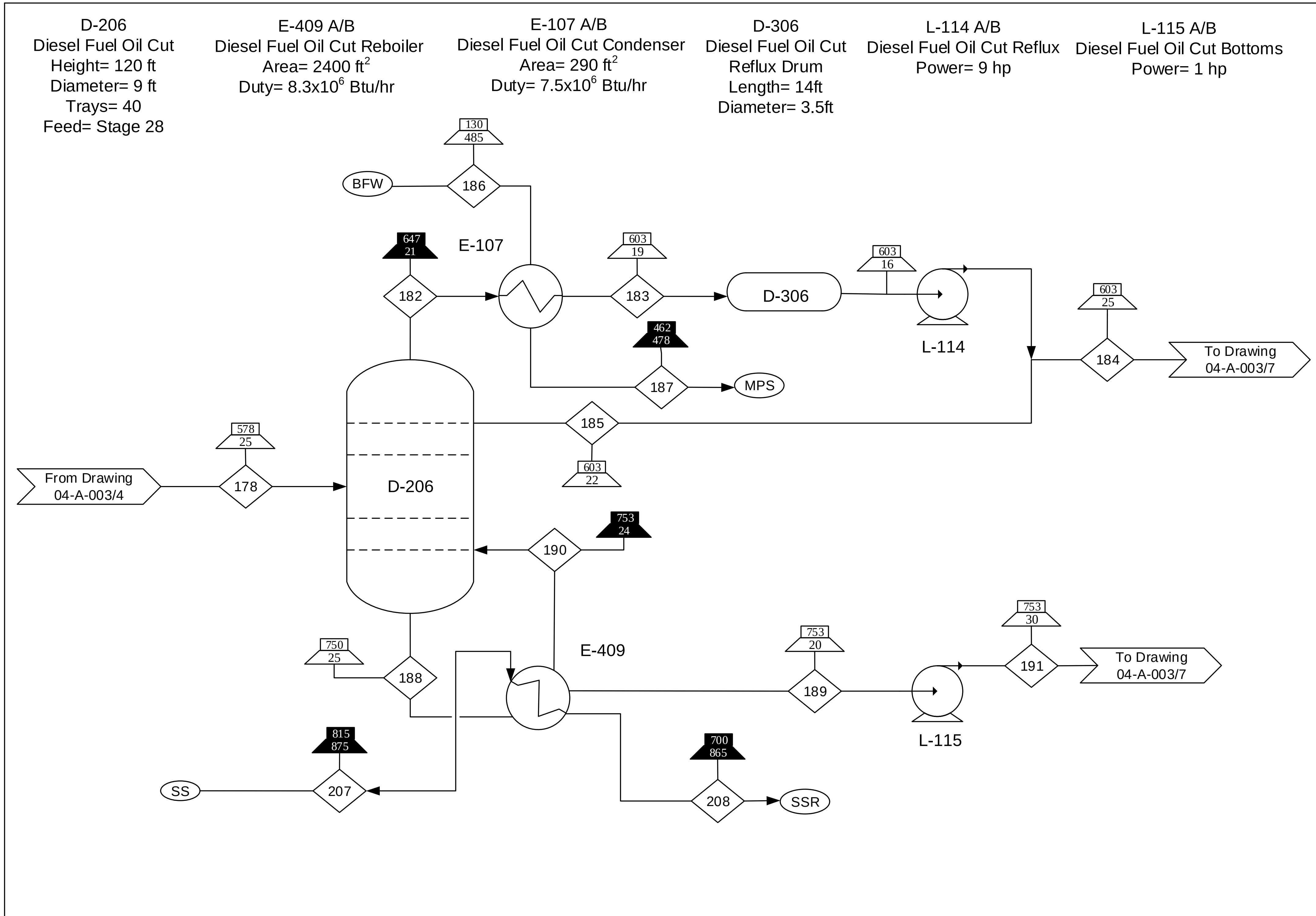
Reference Drawings:

Input/Output Diagam
00-A-001
Block Flow Diagram
00-A-002
Process Flow Diagrams
04-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-3-17	04-A-003/4	0



Component/Stream (lb/min)	178	182	183	184	185	186	187	188	189	190	191	207	208
C16-C30	480	0	0	0	0	0	0	0	0	0	0	0	0
C16-C21	0	830	830	470	360	0	0	0	0	0	0	0	0
C22-C30	0	0	0	0	0	0	0	1400	10	1400	10	0	0
Water	0	0	0	0	0	120	120	0	0	0	0	6700	6700
Total	480	830	830	470	360	120	120	1400	10	1400	10	6700	6700

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
MPS Medium Pressure Steam
BFW Boiler Feed Water
SS Superheated Steam
SSR Superheated Steam Recycle

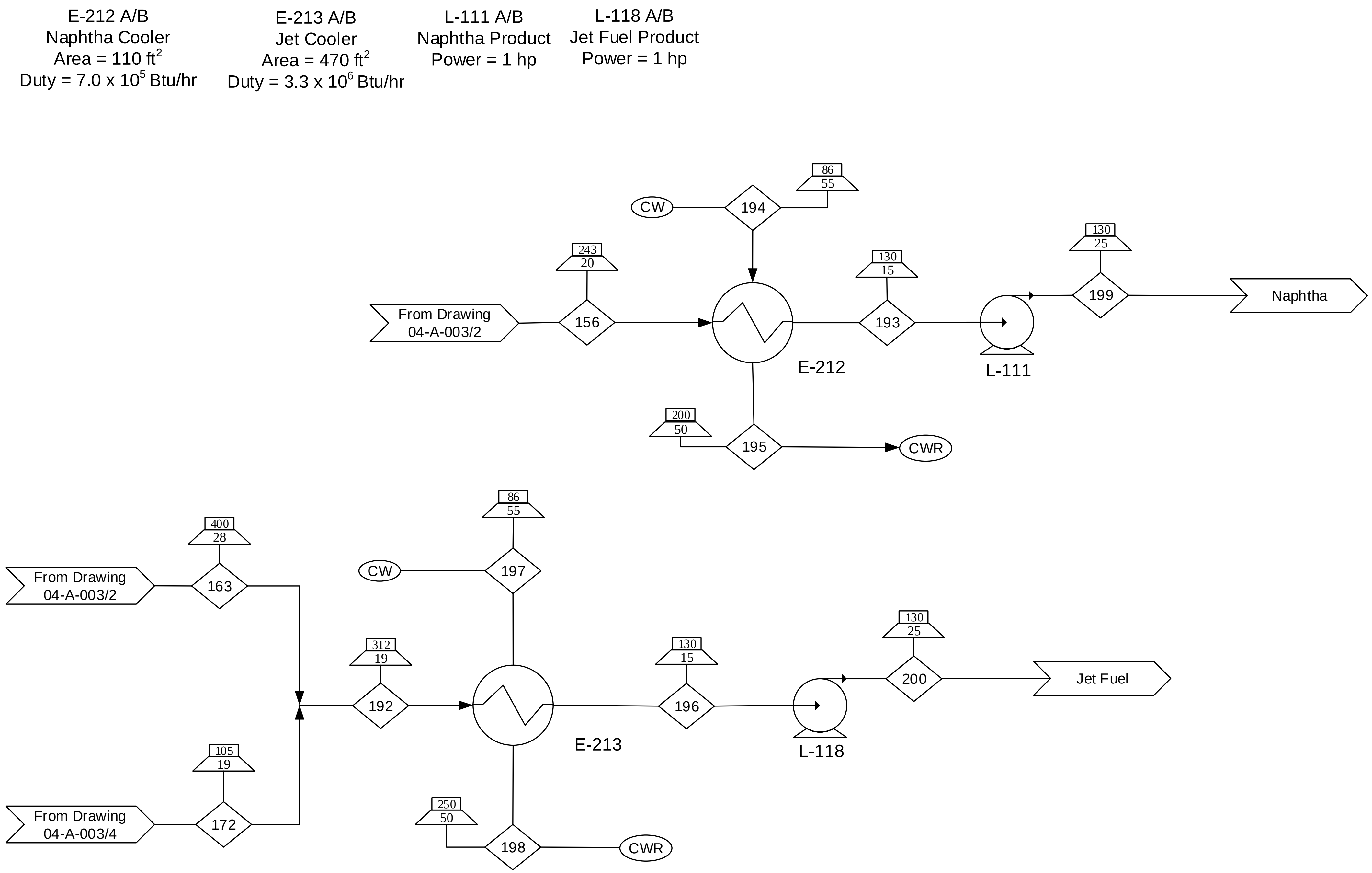
Reference Drawings:

Input/Output Diagram
00-A-001
Block Flow Diagram
00-A-002
Process Flow Diagrams
04-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-3-17	04-A-003/5	0

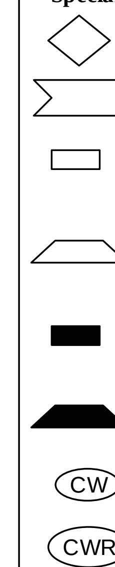


Component/Stream (lb/min)	156	163	172	192	193	194	195	196	197	198	199	200
Naphtha Product	150	0	0	0	150	0	0	0	0	0	150	0
Jet Fuel Product	0	270	160	430	0	0	0	430	0	0	0	430
Water	0	0	0	0	0	430	430	0	2100	2100	0	0
Total	150	270	160	430	150	430	430	430	2100	2100	150	430

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature



Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
CW Cooling Water
CWR Cooling Water Recycle

Reference Drawings:

Input/Output Diagram 00-A-001
Block Flow Diagram 00-A-002
Process Flow Diagrams 04-A-003

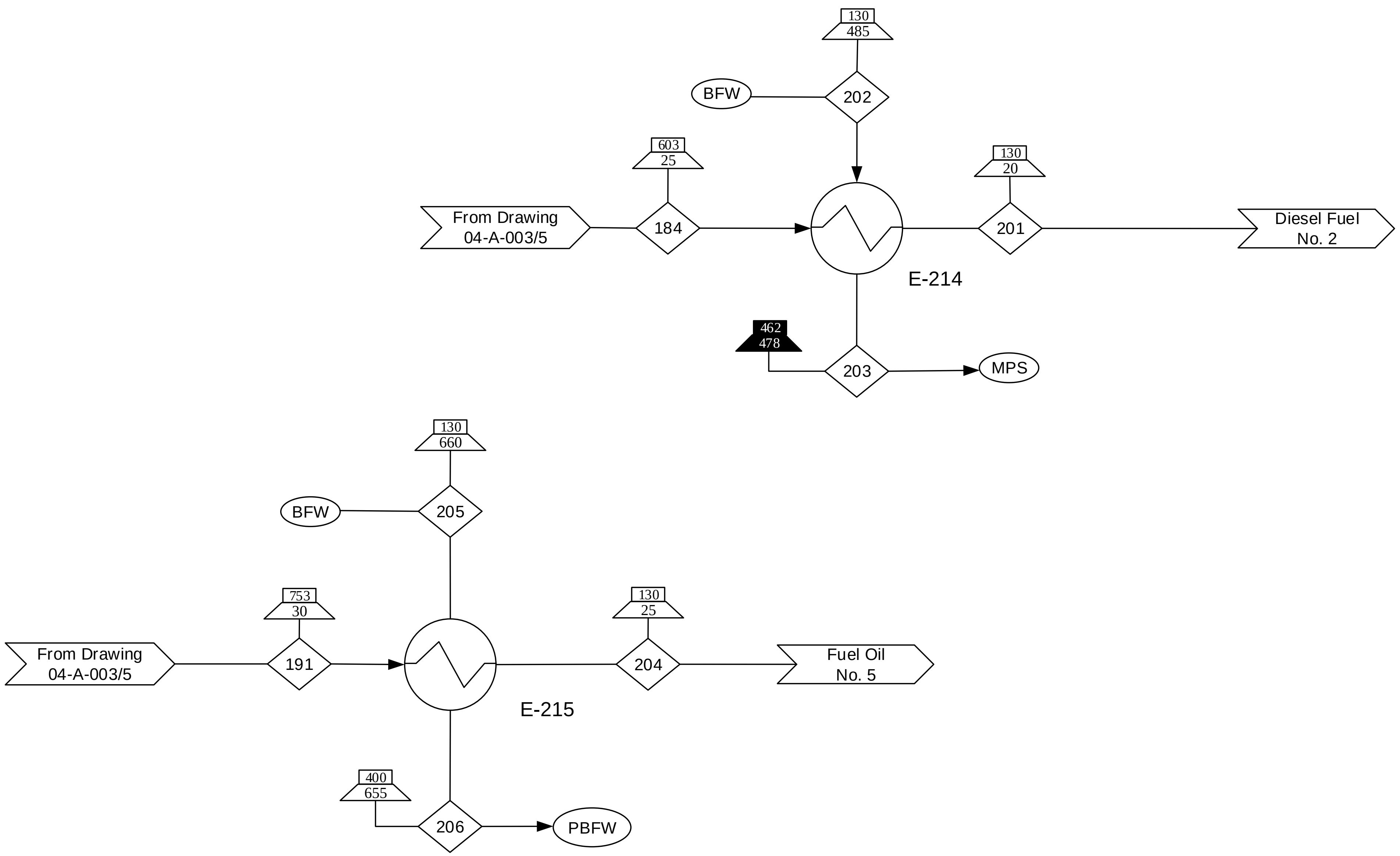
Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-4-17	04-A-003/6	0

E-214 A/B
Diesel Cooler
Area = 1400 ft^2
Duty = 1.1×10^7 Btu/hr

E-215 A/B
Fuel Oil Cooler
Area = 20 ft^2
Duty = 2.8×10^5 Btu/hr

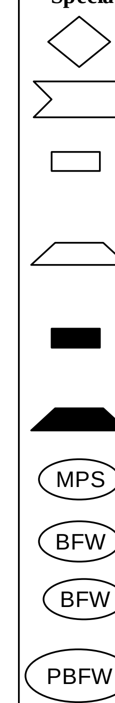


Component/Stream (lb/min)	184	191	201	202	203	204	205	206
Diesel Fuel No. 2 Product	470	0	470	0	0	0	0	0
Fuel Oil No. 5 Product	0	10	0	0	0	10	0	0
Water	0	0	470	170	170	0	50	50
Total	470	10	0	170	170	10	50	50

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature



Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
MPS Medium Pressure Steam
BFW Boiler Feed Water
BFW Boiler Feed Water
PBFW Preheated Boiler Feed Water

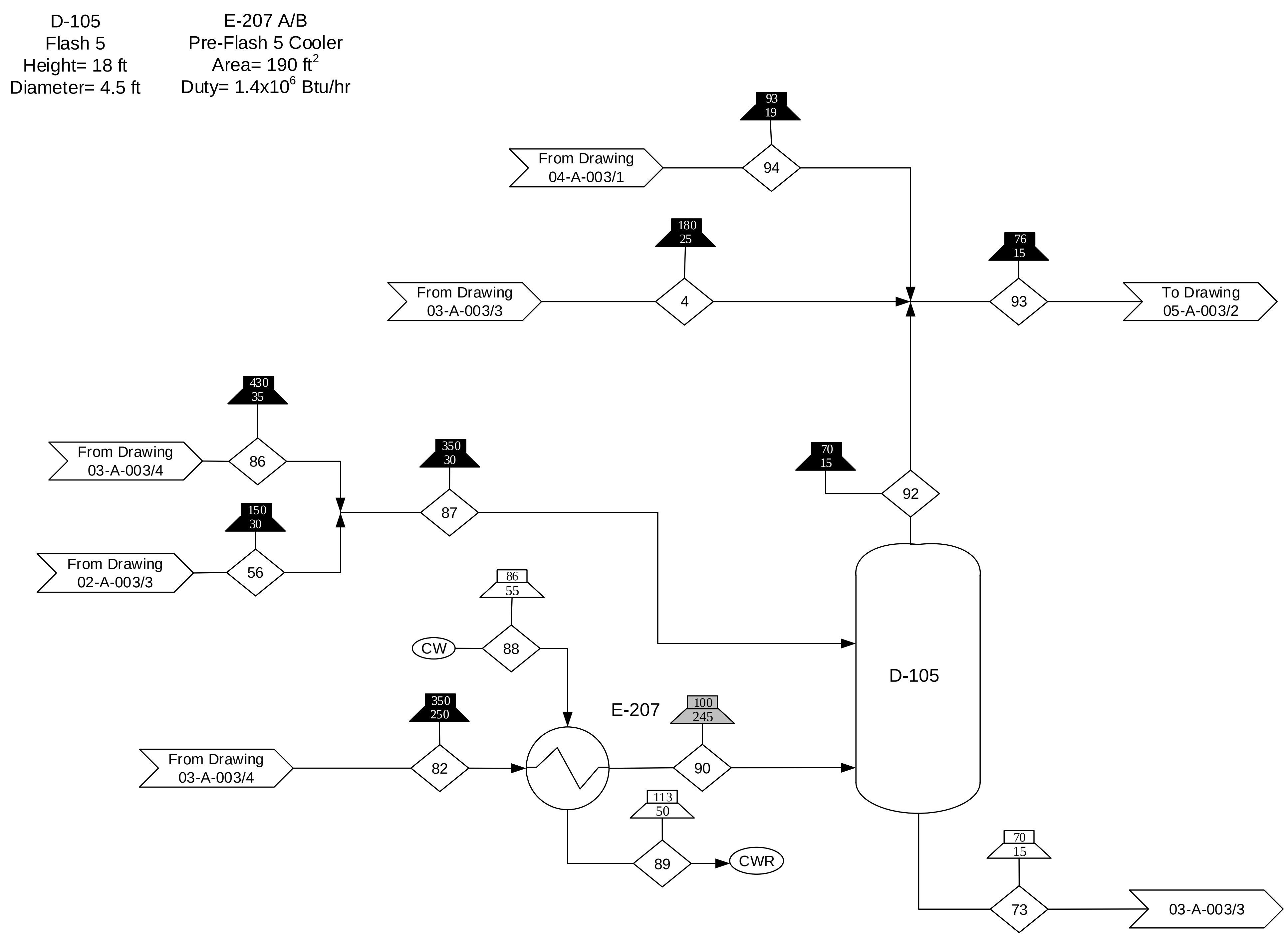
Reference Drawings:

Input/Output Diagram
00-A-001
Block Flow Diagram
00-A-002
Process Flow Diagrams
04-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Trim Purification Section

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-4-17	04-A-003/7	0

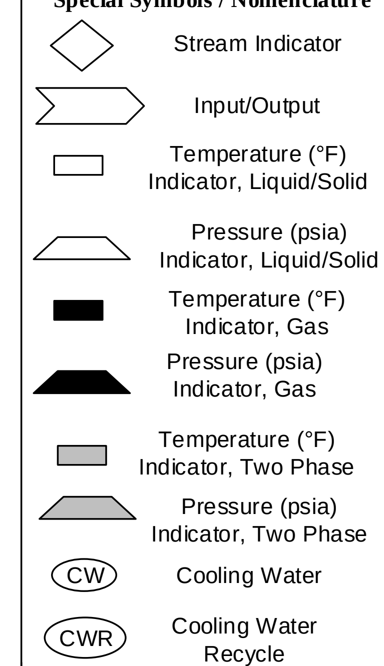


Component/Stream (lb/min)	4	56	73	82	86	87	88	89	90	92	93	94
C1-C2	0	0	0	53	0	0	0	0	53	0	0	0
C3-C7	0	0	0	0	23	0	0	0	0	0	0	0
C1-C7	0	0	0	0	0	0	0	0	0	0	0	0
C1-C6	100	380	0	0	0	400	0	0	0	410	540	30
C6-C7	0	0	50	0	0	0	0	0	0	0	0	0
Water	0	0	0	0	0	0	850	850	0	0	0	0
Total	100	380	50	53	23	400	850	850	53	410	540	30

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



Reference Drawings:

Input/Output Diagram
00-A-001
Block Flow Diagram
00-A-002
Process Flow Diagrams
02-A-003
03-A-003
04-A-003
05-A-003

Drawing Type
Process Flow Diagram

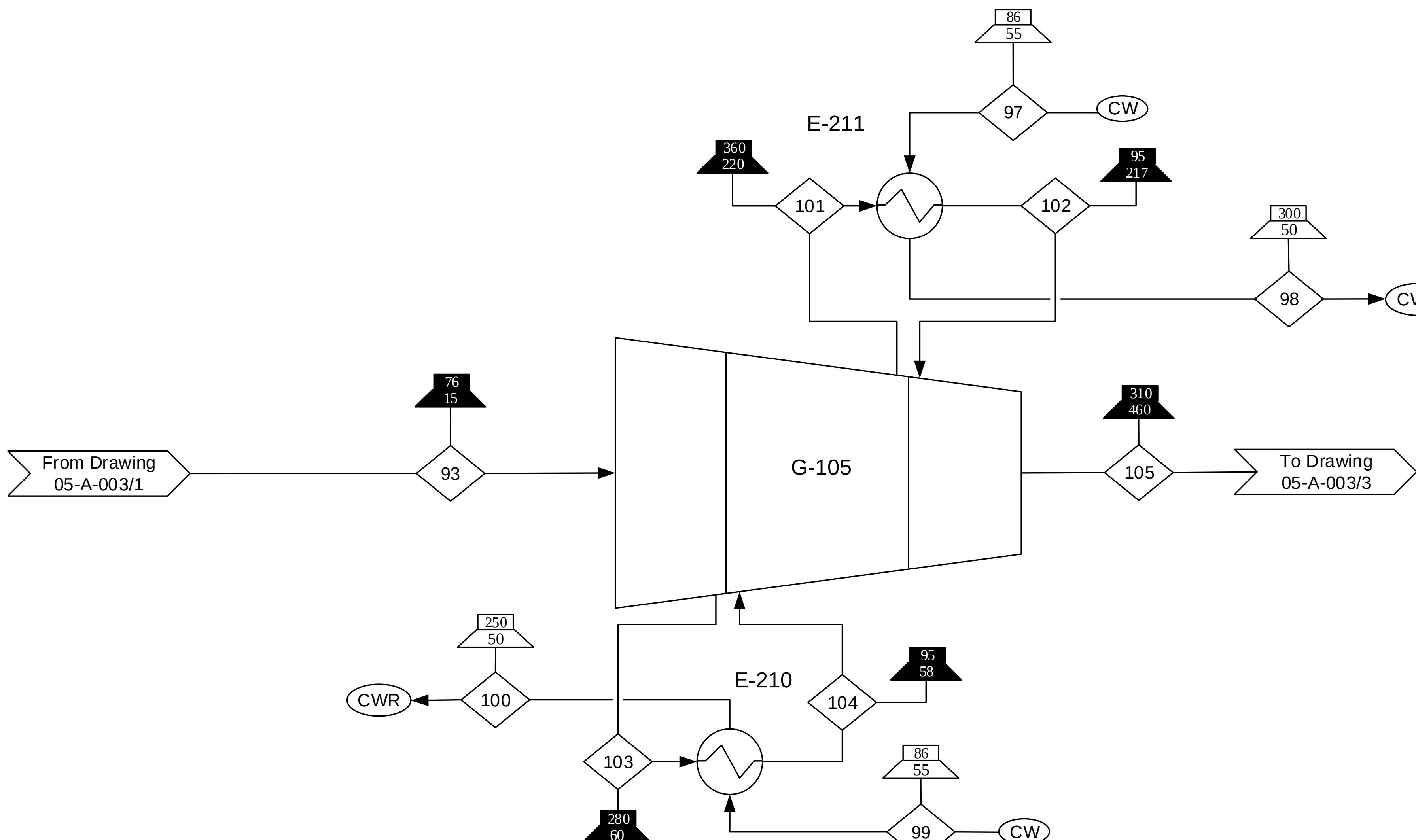
Title
Biorefinery Alternative Base Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 12-29-16	05-A-003/1	0

G-105
Light End Compressor
3 Stages
Stage 1 Power= 1000 hp
Stage 2 Power = 1000 hp
Stage 3 Power = 1000 hp

E-210 A/B
Interstage Cooler 1
Area= 320 ft^2
Duty= 2.3×10^6 Btu/hr

E-211 A/B
Interstage Cooler 2
Area= 190 ft^2
Duty= 2.8×10^6 Btu/hr



Component/Stream (lb/min)	93	97	98	99	100	101	102	103	104	105
C1-C6	540	0	0	0	0	540	540	540	540	540
Water	0	1700	1700	1400	1400	0	0	0	0	0
Total	540	1700	1700	1400	1400	540	540	540	540	540

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/ min.
4. Pumps operate at 65% efficiency.
5. Compressors operate at 55% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
CW Cooling Water
CWR Cooling Water Recycle

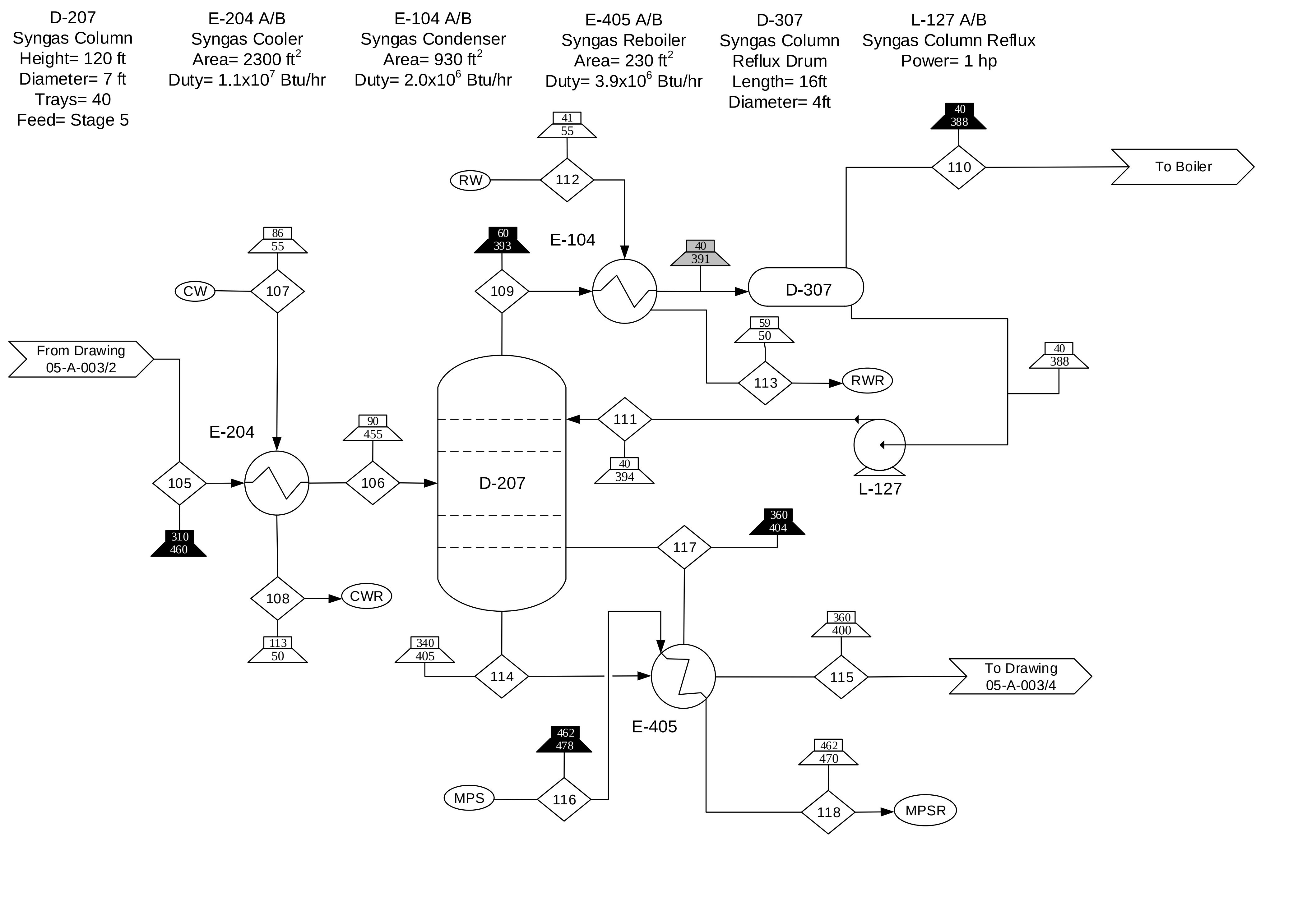
Reference Drawings:

Input/Output Diagram
00-A-001
Block Flow Diagram
00-A-002
Process Flow Diagrams
04-A-003
05-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-2-17	05-A-003/2	0



Component/Stream (lb/min)	105	106	107	108	109	110	111	112	113	114	115	116	117	118
C1-C6	540	540	0	0	0	0	0	0	0	0	0	0	0	0
C1-C3	0	0	0	0	520	350	170	0	0	0	0	0	0	0
C4-C6	0	0	0	0	0	0	0	0	0	780	190	0	590	0
Water	0	0	6600	6600	0	0	0	1200	1200	0	0	85	0	85
Total	540	540	6600	6600	520	350	170	1200	1200	780	190	85	590	85

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
MPS — Medium Pressure Steam
MPSR — Medium Pressure Steam Recycle
RW — Refrigerated Water
RWR — Refrigerated Water Recycle

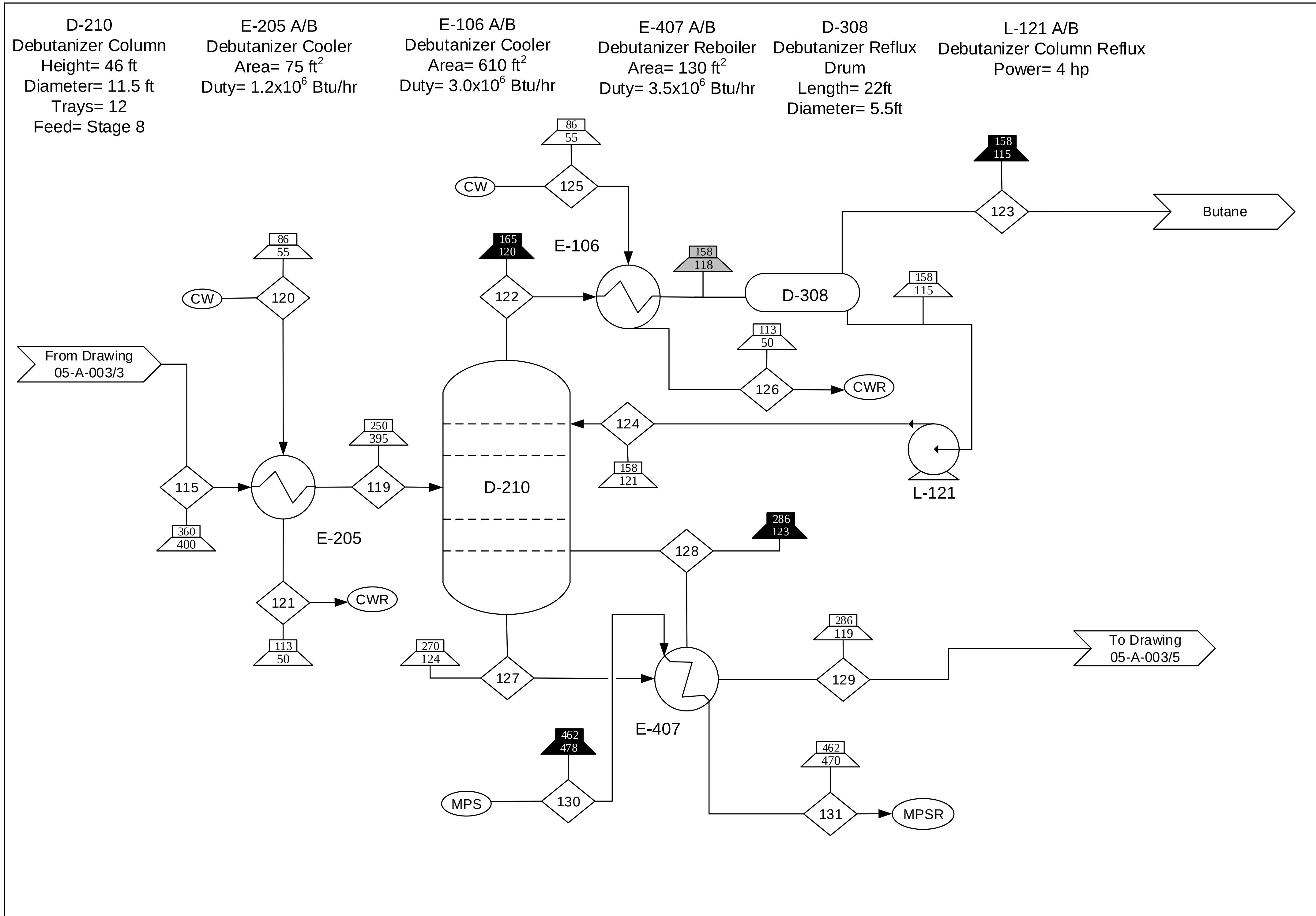
Reference Drawings:

Input/Output Diagram
00-A-001
Block Flow Diagram
00-A-002
Process Flow Diagrams
05-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-2-17	05-A-003/3	0



Component/Stream (lb/min)	115	119	120	121	122	123	124	125	126	127	128	129	130	131
C4-C6	190	190	0	0	0	0	0	0	0	0	0	0	0	0
Butane	0	0	0	0	340	48	290	0	0	0	0	0	0	0
C5-C6	0	0	0	0	0	0	0	0	0	500	350	150	0	0
Water	0	0	760	760	0	0	0	1800	1800	0	0	0	77	77
Total	190	190	760	760	340	48	290	1800	1800	500	350	150	77	77

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.
5. Pumps operate at 65% efficiency.

Special Symbols / Nomenclature

Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
Temperature (°F) Indicator, Two Phase
Pressure (psia) Indicator, Two Phase
MPS Medium Pressure Steam
MPSR Medium Pressure Steam Recycle
CW Cooling Water
CWR Cooling Water Recycle

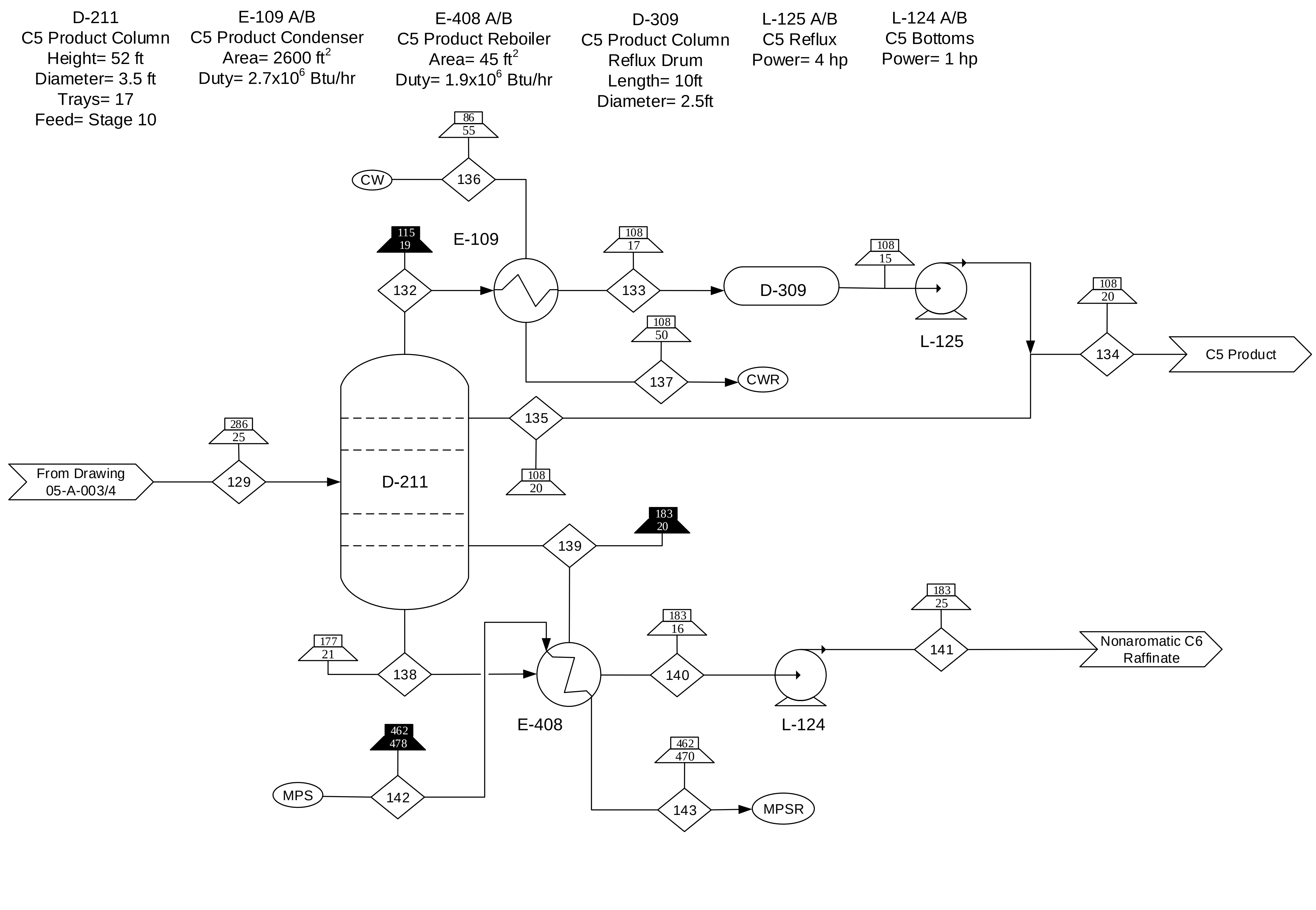
Reference Drawings:

Input/Output Diagram 00-A-001
Block Flow Diagram 00-A-002
Process Flow Diagrams 05-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-2-17	05-A-003/4	0

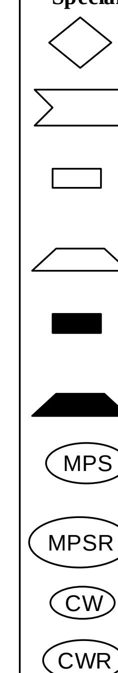


Component/Stream (lb/min)	129	132	133	134	135	136	137	138	139	140	141	142	143
C5-C6	150	0	0	0	0	0	0	0	0	0	0	0	0
C5 Product	0	230	230	54	176	0	0	0	0	0	0	0	0
Nonaromatic C6 Raffinate	0	0	0	0	0	0	0	175	82	93	93	0	0
Water	0	0	0	0	0	1700	1700	0	0	0	0	41	41
Total	150	230	230	54	176	1700	1700	175	82	93	93	41	41

Notes

1. Drawing is not to scale.
2. Mass balances may be off due to rounding.
3. Mass balances are shown in lb/min.
4. Pumps operate at 65% efficiency.
5. C1-C50 in the mass balance refers to the number of carbons in molecule chains the fuel streams.

Special Symbols / Nomenclature



Stream Indicator
Input/Output
Temperature (°F) Indicator, Liquid/Solid
Pressure (psia) Indicator, Liquid/Solid
Temperature (°F) Indicator, Gas
Pressure (psia) Indicator, Gas
MPS Medium Pressure Steam
MPSR Medium Pressure Steam Recycle
CW Cooling Water
CWR Cooling Water Recycle

Reference Drawings:

Input/Output Diagram 00-A-001
Block Flow Diagram 00-A-002
Process Flow Diagrams 05-A-003

Drawing Type
Process Flow Diagram

Title
Biorefinery Alternative Base Design – Light End Processing

By/Date	DWG #/ Sheet #	Rev
SAB/ 1-3-17	05-A-003/5	0

Appendix J. Representative ChemCad Chemical Composition

Table J-1 shows the representative composition out of the TTCR generated by ChemCad. These components were taken from experimental data. The experimental run that produced the most liquid crackate was used as a reference (H-soy). The conditions of this experimental run were a residence time of 1.17 hours and a temperature of 430 °C [10].

Table J.1. Representative ChemCad Composition Used to Model the TTCR Reactions

Name		**H-Soy**
Water	wt. %	0.000
Hydrogen		0.001
Carbon Monoxide		0.025
Carbon Dioxide		0.053
Methane		0.004
Ethane		0.010
Propane		0.010
Butane		0.013
Pentane		0.007
Hexane		0.007
Heptane		0.010
Octane		0.009
Nonane		0.009
Decane		0.005
Undecane		0.005
Dodecane		0.005
Tridecane		0.006
Tetradecane		0.006
Pentadecane		0.013
Hexadecane		0.004
Heptadecane		0.006
Octadecane		0.003
Nonadecane		0.030
Eicosane		0.033
Uneicosane		0.024
Docosane		0.018
Tricosane		0.018
Tetracosane		0.015
Pentacosane		0.013
Hexacosane		0.014

(continued)

Table J.1. Cont.

Name		**H-Soy**
Heptacosane	wt. %	0.010
Octacosane		0.009
Nonacosane		0.008
Triacontane		0.011
Dotriacontane		0.027
Tetratriacontane		0.017
Hexatriacontane		0.012
Octatriacontane		0.009
Tetracontane		0.007
Dotetracontane		0.006
Tetratetracontane		0.004
Hexatetracontane		0.006
Octatetracontane		0.003
Pentacontane		0.005
Dopentacontane		0.002
2-Methyloctane		0.001
2-Methyltetradecane		0.001
Cyclopentene		0.005
Methylcyclopentane		0.006
Ethylcyclopentane		0.007
Propylcyclopentane		0.006
Butylcyclopentane		0.005
Butylcyclohexane		0.006
Hexylcyclopentane		0.008
Heptylcyclopentane		0.005
Octylcylopentane		0.005
Nonylcyclopentane		0.005
Decylcyclopentane		0.005
Decylcyclohexane		0.006
Dodecylcyclopentane		0.009
Tridecylcyclopentane		0.004
Ethylene		0.002
Propylene		0.005
1-Butene		0.007
1-Pentene		0.008
1-Hexene		0.010
1-Heptene		0.013
1-Octene		0.011
1-Nonene		0.008
1-Decene		0.010
1-Undecene		0.012
1-Dodecene		0.008

(continued)

Table J.1. Cont.

Name		**H-Soy**
1-Tridecene	wt. %	0.007
1-Tetradecene		0.008
1-Pentadecene		0.008
1-Hexadecene		0.010
1-Heptadecene		0.015
1-Octadecene		0.007
Toluene		0.001
Ethylbenzene		0.002
Propylbenzene		0.002
Butylbenzene		0.004
Pentylbenzene		0.007
Hexylbenzene		0.006
Heptylbenzene		0.006
Octylbenzene		0.007
Nonylbenzene		0.007
Decylbenzene		0.008
Undecylbenzene		0.010
Dodecylbenzene		0.009
Acetic Acid		0.006
Propionic Acid		0.002
Butyric Acid		0.002
Pentanoic Acid		0.004
Hexanoic Acid		0.007
Heptanoic Acid		0.017
Octanoic Acid		0.012
Nonanoic Acid		0.013
Decanoic Acid		0.012
Undecanoic Acid		0.005
Dodecanoic Acid		0.004
Tridecanoic Acid		0.004
Tetradecanoic Acid		0.004
Pentadecanoic Acid		0.004
Hexadecanoic Acid		0.022
Heptadecanoic Acid		0.005
Octadecanoic Acid	wt. %	0.021
Asphaltenes		0.051
Coke		0.000

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